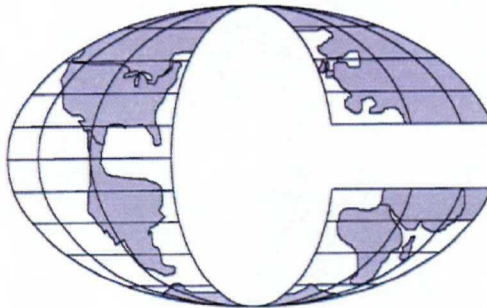


Prepared for
Pedricktown Site Group

**FOCUSED FEASIBILITY STUDY
FOR
GROUNDWATER REMEDIATION
NL Industries Superfund Site
Pedricktown, New Jersey**

**November 2007
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EXECUTIVE SUMMARY

The Focused Feasibility Study (FFS) Report describes current groundwater conditions at the NL Industries, Inc. Superfund Site (Site), located in Pedricktown, New Jersey, and potentially applicable techniques to address groundwater impacts. The FFS report provides recommendations for the selection of the technologies that are anticipated to improve groundwater quality at the Site.

The Site was formerly used by several companies for lead-acid battery recycling and secondary lead reclamation. The processes used in battery recycling and lead reclamation resulted in the release of acid from batteries and other materials. Some of the materials released contained lead and cadmium, which affected groundwater. The bulk of the lead and cadmium was adsorbed in soil. More than 150,000 tons of impacted soil was excavated, stabilized and disposed off-Site during the remedial action for soil that was completed in May 2003.

The remedial alternatives for groundwater evaluated in the FFS Report include the following:

- No Action;
- Monitored Natural Attenuation (MNA);
- Reagent Injection;
- Permeable Reaction Barriers; and
- Pump and Treat.

The remedial alternatives were evaluated using United States Environmental Protection Agency (EPA) criteria. The selection of technologies for evaluation was based primarily on the ability to implement the technologies, anticipated effectiveness, and projected cost.

1. INTRODUCTION

1.1 Purpose and Goal

The focused feasibility study for groundwater at the NL Industries, Inc. Superfund Site (Site) and the remedy evaluation process described in this document is consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).¹ As stated within the NCP, “[t]he purpose of the remedy selection process is to implement remedies that eliminate, reduce, or control risks to human health and the environment.”² The goal of the process “is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste.”³ Thus, the focused feasibility study presented within this document was performed to systematically evaluate potential groundwater remedies for the Site to meet the objectives of the NCP.

1.2 Background Information

1.2.1 Site Description

The Site is located to the north of the Pennsgrove-Pedricktown Road, in Pedricktown, Oldmans Township, Salem County, New Jersey. The Site location is shown on Figure 1 and the Site overview is shown on Figure 2. The 44-acre (18-hectare) Site is bordered on the south by Pennsgrove-Pedricktown Road and is bisected by an active railroad (i.e., Conrail Right-of-Way). Approximately 16 acres (6 hectares) are located north of the railroad, including a closed, 5.6-acre (2.2-hectare) landfill operated and maintained by NL Industries, Inc. (NL Industries). The southern 28 acres (11 hectares) contain the former NL Industries process area and the NL Industries landfill access road. NL Industries maintains the closed landfill area and operates the leachate collection system.

The West and East Streams, which are reported in the Record of Decision (ROD) for the NL Industries Superfund Site [United States Environmental Protection Agency (EPA) 1994] to be intermittent tributaries to the Delaware River, border the Site to the west and east, respectively. These streams are also reported by the EPA to receive runoff from the Site. Industrial properties are located east of the former NL Industries process area, as indicated in the Feasibility Study (FS) prepared by O’Brien & Gere Engineers, Inc. (O’Brien & Gere), of Edison, New Jersey [1993] for NL Industries. U.S. Route 130 is located north of the Site. Several residential properties are located adjacent to and west of the West Stream. Other properties in the general vicinity of the Site are used for commercial, residential, agricultural, and military purposes.

¹ 40 C.F.R. § 300 *et seq.*

² 40 C.F.R. § 300.430(a)(1)

³ 40 C.F.R. § 300.430(a)(1)(i)

1.2.2 Site History

The Site was used for lead-acid battery recycling and secondary lead reclamation between 1972 and 1984. NL Industries operated a secondary smelting, battery breaking, and lead recycling facility at the Site beginning in 1972. The process involved crushing of spent lead-acid batteries to separate the components of the batteries, draining the sulfuric acid from the batteries, and then processing the material for lead recovery at the smelting facility. According to the Remedial Investigation (RI) [O'Brien & Gere, 1990] and FS reports, wastes resulting from the battery-crushing operation and slag from the smelting process were disposed in the landfill located at the Site.

NL Industries ceased smelting operations in May 1982. In October 1982, NL Industries entered into an Administrative Consent Order (ACO) with the New Jersey Department of Environmental Protection (NJDEP) to remediate contaminated Site soils, paved areas, surface-water runoff, the on-Site landfill, and groundwater. In December 1982, the Site was placed on the National Priorities List (NPL) by the EPA. National Smelting of New Jersey (NSNJ) bought the facility and performed smelting operations at the Site between February 1983 and January 1984. NSNJ ceased operations in January 1984 and filed for bankruptcy in March 1984. In April 1986, NL Industries entered into an ACO with the EPA, in which NL Industries assumed responsibility for conducting, with EPA oversight, an RI and FS for the Site.

The EPA performed a multi-phased Removal Action at the Site beginning in March 1989. A total of five phases of work were performed including:

- Phase I - fence installation and encapsulation of slag piles;
- Phase II - additional encapsulation of slag and removal of 20 tons of material;
- Phase III - stormwater control improvements;
- Phase IV - slag bin retaining walls repair; and
- Phase V - removal of contaminated sediments from the West Stream.

Phase V of the EPA Removal Action was initiated in the fall of 1993 and was scheduled for completion in the summer of 1994. In 1991 during the Removal Action, the EPA notified potentially responsible parties (PRPs) of their potential liability for contamination and for response costs associated with remediation of the Site.

While RI/FS activities were being performed, the EPA also divided the Site into two operable units, (Operable Units (OUs) 1 and 2), completed a Focused Feasibility Study (FFS) for a portion of OU2, and issued a ROD and Explanation of Significant Differences for OU2. In response to a Unilateral Administrative Order (UAO) issued by EPA in March 1992, a group of PRPs commenced response activities for OU2. The response action for OU2, completed in September 1995, included off-Site reclamation of certain lead-containing materials, solidification/stabilization and off-Site disposal of slag and other materials, decontamination of building floors and surfaces, off-Site treatment

and disposal of contaminated standing water, building demolition, and environmental monitoring. Activities related to OU1 are described below.

To evaluate the extent of contamination and remediation alternatives for the Site, O'Brien & Gere performed an RI [1990] followed by an FS [1993] on behalf of NL Industries. Based on these investigations, EPA issued a ROD in July 1994 that specified selected remedies for remediation of soil, sediment, and groundwater at the Site. In June 1996, the EPA issued an AOC for Remedial Design (RD), which directed the Pedricktown Site Group ("Group," which is a coalition of several PRPs) to design the remedy for OU1 which included soil, stream sediment, and groundwater, as specified in the ROD. The AOC included a Statement of Work that provided requirements for the pre-design investigation and RD activities.

The Group retained GeoSyntec Consultants (GeoSyntec) of Columbia, Maryland to perform a pre-design field investigation and develop the RD for the Site. The RD for soil and sediment was submitted to and approved by the EPA in January 2000. In February 2000, the Group retained ENTACT, Inc. to perform remedial activities for soil and sediment in accordance with the RD. ENTACT began performing the RA in June 2000. The RA was completed in May 2003. CSI performed quality assurance oversight of the RA activities along with a representative of the United States Army Corps of Engineers (ACOE), who represented the EPA's interests.

The focus of the RA was to achieve the following Remedial Action Objectives (RAOs):

- Excavate soil with lead concentrations greater than 500 parts per million (ppm);
- Remove contaminated sediment containing lead concentrations greater than 500 ppm from the East Stream, West Stream and channel north of U.S. Route 130;
- Stabilize the excavated soil and sediment; and
- Dispose of the stabilized soil and sediment in an approved off-Site disposal facility.

A total of 150,928 tons of treated soil and sediment were disposed of at the Gloucester County landfill, Cumberland County landfill and the Atlantic County landfill. The soil and sediment were treated on Site using either dolomitic lime or EnviroBlend. The landfills utilized the treated soil and sediment as daily cover. In addition, the concrete foundation from the former smelting facility was demolished and the concrete removed from the Site. Approximately 10,887 tons of concrete was shipped off-Site. Another approximately 182 tons of scrap metal, 35 tons of miscellaneous debris and 24 tons of decontaminated railroad ties were also removed from the Site during the RA. ENTACT documented the RA efforts in an Interim Remedial Action Report [ENTACT, July 2003].

CSI performed the initial post-RA groundwater monitoring event in January 2004. Subsequently, CSI performed a second round of groundwater monitoring at the Site in April 2007. The post-RA groundwater sampling events were documented in two reports

entitled *Groundwater Monitoring Report* produced by CSI in April 2004 and September 2007.

In addition to monitoring groundwater quality on the Site, CSI collected potable water samples from private wells at five residences and one commercial property located along Route 130 on three separate occasions (January 2004, April 2006 and April 2007). The laboratory data obtained in 2007 from these residences confirmed previous conclusions that lead and cadmium concentrations were, as stated by the EPA after the April 2006 event, either not detectable or significantly below New Jersey drinking water quality standards. Furthermore, after evaluating the April 2007 groundwater elevation data (shown on Figure 3), CSI confirmed its belief that shallow groundwater in the vicinity tends to flow toward local surface water bodies as previously reported. These surface water bodies include the West Stream, East Stream and a series of wet areas located between the NL Industries landfill and the Kucowski-Ahamd and Hodge (Delaware River Landing Company LLC) properties (see Figure 3). CSI also determined that the surface water bodies are believed to be hydrogeologic barriers to shallow groundwater flow between the Site and the businesses and residences located along Route 130.

Monitoring wells 13, 14, 15, 16, and 17 are located at the Site (Figure 3) in the area between the former operations areas and the residential and commercial properties located along Route 130. Groundwater samples obtained from the monitoring wells were also analyzed for lead and cadmium as part of the on-going groundwater evaluation of the Site. Data from monitoring wells 13, 14, 15, 16, and 17 are provided in Table 1. As reported on Table 1, neither lead nor cadmium was detected in the groundwater samples.

1.2.3 Nature and Extent of Contamination

Soil and Sediment

As summarized in the ROD, the results of the RI revealed that lead was formerly detected in soil at concentrations up to 12,700 parts per million (ppm) within the NSNJ property limit and 1,770 ppm in soil located outside of the property limit. Although several other metals were detected in soil, lead was the most prevalent and was defined in the ROD as the primary contaminant of concern (COC) [EPA, 1994]. Lead concentrations in the East and West Stream sediments ranged from 5 to 59,700 ppm, respectively [O'Brien & Gere, 1990]. The highest concentrations were detected in the West Stream sediment adjacent to the former facility.

Contaminated soil and sediment were excavated by ENTACT during remedial activities that were performed from 2000 to 2003. After remedial activities were completed, CSI conducted sediment sampling in the West Stream in November 2005 and supplementary sediment sampling in June 2006 and April 2008. The results of the sampling events were presented in three separate letter reports submitted to EPA in January 2006, August 2006, and July 2008. Based upon these data, additional sediment must be removed from the West Stream to meet the 500 ppm performance standard set by

EPA in the ROD. However, it is not anticipated that the trace concentrations of lead that may remain in the shallow surface sediments of the West Stream at the Site will have any impact on groundwater. Sediment remediation is not addressed in this FFS Report.

Surface Water

During the RI, several inorganic constituents were detected in the surface water in the East and West Streams and in the channel north of U. S. Route 130 at varying, but generally low, concentrations. Lead, however, was detected in the surface water samples obtained from the East and West Streams, at concentrations ranging from 10 micrograms per liter ($\mu\text{g/L}$) to 2,200 $\mu\text{g/L}$ in 1989 and at concentrations ranging from 4 $\mu\text{g/L}$ to 206 $\mu\text{g/L}$ in 1990, respectively. These concentrations exceeded EPA's Ambient Surface Water Quality Criterion of 3.2 $\mu\text{g/L}$ for lead, which is the concentration that is estimated to be protective of aquatic life based on chronic toxicity. As noted in the ROD, the EPA anticipated that remediation of contaminated soil and sediment would also satisfactorily address lead in the surface water.

Groundwater

The information presented in the RI indicates that the Site is underlain by three hydrogeologic units that were identified as the unconfined (i.e., water table) aquifer, the first confined aquifer, and the second confined aquifer [O'Brien & Gere, 1990]. In addition to on-Site groundwater monitoring, groundwater evaluations performed as part of the RI included sampling potable water from wells at residences along Route 130 to the north of the Site in 1988 and 1989. Also, the EPA sampled the residential potable wells in August 1988 and July 1989. The results of the potable well sampling events indicated that the groundwater at the residences had not been adversely impacted.

The groundwater monitoring activities included in the RI were conducted in 1988 and 1989. At that time, fifty-two wells (on-Site and off-Site) were sampled, with the majority of these being sampled during both events. The groundwater samples were analyzed for antimony, arsenic, cadmium, chromium, copper, lead, selenium, chloride, sulfate, total organic carbon, and total organic halogens. A subset of forty-four monitoring wells was also analyzed for radiological parameters. Based upon the 1988 results, additional radiological and volatile organic compound analyses were conducted during the 1989 sampling in specific areas to further evaluate the 1988 data.

Site-related contaminants were detected in the groundwater of the unconfined aquifer at the Site during the RI and the data indicated that the contamination in groundwater was limited to the unconfined aquifer. The contaminants detected in the unconfined aquifer were comprised primarily of lead; however, volatile organic compounds (VOCs) and radiological parameters were also detected in localized areas of the Site. Specifically, hydrocarbon related compounds were detected in monitoring well SD and chlorinated compounds were detected primarily in monitoring well 11. The hydrocarbon and chlorinated compounds were anticipated to naturally attenuate in a relatively short time frame. The radiological parameter analysis did not indicate a

radionuclide source at the Site as there was no clear pattern of radionuclide occurrence in the subsurface (O'Brien and Gere, 1990). It was suggested that the radionuclide source may have been naturally occurring because of the detection of elevated gross alpha and beta activity adjacent to clay layers at the Site. However further study was recommended, which was later performed as described below.

Arsenic was detected at elevated concentrations in monitoring well 2R2 during the RI. However, monitoring well 2R2 was located in the vicinity of leachate collection devices and leachate seeps related to the NL Industries landfill. The arsenic detected was believed to be related to landfill leachate, which contained high concentrations of arsenic. Subsequent improvements were made by NL Industries to the landfill, eliminating the seeps. Other metals detected in groundwater at lower concentrations included beryllium, chromium, copper, nickel, and zinc.

As part of the RD, the Group performed two phases of groundwater evaluations and reported the results to the EPA in *Phase I Groundwater Evaluation Technical Memorandum* (Phase I Technical Memorandum) [GeoSyntec, 1998] and *Phase II Groundwater Evaluation Technical Memorandum* (Phase II Technical Memorandum) [GeoSyntec, 2000]. The results presented in both documents support the findings that the area of impacted groundwater is stationary at the Site and that the mass of contaminants in groundwater is declining. The Phase I and II Technical Memoranda are incorporated herein by reference.

The Phase I evaluations were conducted in September and October 1997 and included the collection of twenty groundwater samples that were analyzed for sulfates, VOCs, semi-volatile organic compounds (SVOCs), total and dissolved metals, cyanide, and radiological parameters. All samples also were monitored for the water quality parameters pH, specific conductivity, oxidation-reduction potential, dissolved oxygen, and turbidity. The Phase I Technical Memorandum identified the relationship between pH and the presence of lead and cadmium in groundwater. It was noted that the lower pH groundwater historically contained more elevated concentrations of lead and cadmium.

The analytical results described in the Phase I Technical Memorandum indicated, in general, that the concentrations of COCs in groundwater at the Site decreased since the late 1980s when the RI was conducted. Specifically, lead concentrations in the central portion of the Site dropped significantly. In samples obtained from monitoring well KS, lead concentrations fell from 3,130 µg/L to 328 µg/L and in the samples obtained from monitoring well SD, lead concentrations declined from 2,960 µg/L to 51 µg/L. Similar reductions in the concentrations of lead and cadmium were noted across the Site. Furthermore, it was noted that previously measured high concentrations of lead had not migrated to downgradient locations but instead remained in the central portion of the Site. A decline in concentrations and lack of migration were shown to be true for cadmium as well [GeoSyntec, 1998].

Through the Phase I and II evaluations, cadmium and lead were again found to be the only inorganic constituents that were detected at elevated concentrations. Several

other inorganic constituents were detected at isolated locations, but they were not detected at concentrations that warranted further action. Based upon the Phase I data, it was recommended that the only inorganic constituents to be evaluated during the Phase II evaluations should be total lead and cadmium.

The VOC and SVOC concentrations in groundwater reported in the Phase I Technical Memorandum were lower than the concentrations reported during the RI with the exception of vinyl chloride at well 12. The decreased concentrations for all other VOCs and SVOCs support the conclusion presented in the RI that these compounds would naturally attenuate. Because of the lack of detection of SVOC constituents, the Phase I Technical Memorandum included a recommendation that there was no need to analyze the groundwater for SVOCs during the Phase II evaluations.

The radiological parameter results presented in the evaluations performed and reported as part of the Phase I Technical Memorandum were equivocal as they contained a high degree of uncertainty (i.e. large margin errors). In general, the measured occurrence of radiological isotopes decreased from those measured in 1988 and 1989. However, because the data were equivocal, it was recommended in the Phase I Technical Memorandum that further evaluation of radiological parameters be included in the Phase II evaluations.

The evaluations that culminated in the Phase II Technical Memorandum were designed to close data gaps identified in the Phase I Technical Memorandum and to further assess potential remedial alternatives for groundwater. Specifically, the evaluations included (i) the installation of additional monitoring wells as recommended by the EPA; (ii) sampling of on-Site and off-Site monitoring wells, including potable groundwater from residential wells along Route 130; (iii) assessment of the former septic beds as a potential source of contamination; (iv) aquifer testing; (v) evaluation of the likely capture zone of groundwater extraction wells, if they were installed; (vi) geochemical evaluation of Site subsurface soils; and (vii) groundwater flow and transport modeling [GeoSyntec, 2000]. The results of these Phase II evaluations are discussed below and in Section 1.2.4, *Contaminant Fate and Transport*.

To investigate areas of the Site that had not been previously studied, twelve new monitoring wells were installed. The wells were installed in locations and at depths recommended by the EPA. During the Phase II evaluations, the twelve new monitoring wells were sampled along with twelve existing wells using low-flow sampling techniques. The samples were analyzed for VOCs and total and dissolved lead and cadmium. The new monitoring wells and Exxon Well No. 2 were also analyzed for radiological and general chemistry parameters. In addition, during purging and sampling activities, the water quality parameters pH, temperature, specific conductivity, oxidation-reduction potential, dissolved oxygen, and turbidity were monitored.

Significant findings of the Phase II evaluations were related to pH and turbidity. An analysis of the trends in historical groundwater pH, as depicted in a series of figures presented in Appendix D, showed that the area of low groundwater pH was decreasing.

As the groundwater pH trends upward to more neutral conditions, the area of impacted groundwater containing lead and cadmium decreased and is anticipated to continue to decrease. Additionally, the relationship between turbidity and analytical data (which showed that as the turbidity of groundwater samples increased, the concentrations of total lead and cadmium also increased) was further demonstrated.

The analytical results for VOCs presented in the Phase II Technical Memorandum confirmed the findings of the Phase I Memorandum and the RI. Concentrations of VOCs continued to decline relative to previous sampling events. The only exception was the detection of vinyl chloride in monitoring wells 12 and 24. Monitoring wells 12 and 24 are screened in the first confined aquifer and are closest to the nearby Exxon property. The vinyl chloride detections were believed to be unrelated to the Site as no Site uses are known sources of vinyl chloride or related chlorinated organic compounds. The Exxon property is listed in the NJDEP *Known Contaminated Sites in New Jersey for Salem County, Seventh Edition* (Spring 2006) and is also mentioned along with B.F. Goodrich in the ROD for the Site as a neighboring industrial facility in the vicinity of these wells.

Additionally, an investigation of the former septic beds, located in the southwestern corner of the Site along the Pennsgrrove-Pedricktown Road, was conducted to determine if the septic system beds were a potential source of VOCs downgradient of this location. Soil samples were obtained from borings drilled into the former septic beds. Monitoring wells 31 and 32 were installed adjacent to and downgradient from the septic beds. The results of the septic bed investigation revealed no significant VOC detections in soil or groundwater samples.

The inorganic analyses presented in the Phase II Technical Memorandum also confirmed the results provided in the Phase I Technical Memorandum and the RI. The Phase II data showed concentrations of lead in groundwater above the RAO at five monitoring wells including OS, SD, 27, 28 and 30. Concentrations of cadmium in groundwater above the RAO were detected at 12 of the 24 monitoring wells sampled. The concentrations of lead and cadmium detected during the Phase II evaluation were generally lower than their respective concentrations found during the prior investigations.

To further evaluate the trend, zones of impact were depicted for historical data similar to those shown on Figures 4 and 5. The zones of impact and the concentrations of lead and cadmium within the zones of impact were used to calculate the approximate masses of lead and cadmium remaining in groundwater at the Site. The mass of lead in groundwater at the Site was estimated to have declined from approximately 220 lbs in 1983 to 8.8 lbs in 1998. The mass of cadmium in groundwater at the Site was estimated to have declined from approximately 70.5 lbs in 1988 (earliest available cadmium data) to 14.1 lbs in 1998 [GeoSyntec, 2000].

The results of the Phase II potable well sampling conducted at the residences along Route 130 varied slightly from the results of the Phase I Memorandum and RI studies. The residential sampling event resulted in the detection of total lead at concentrations above the RAO at three residences. However, the RAO was not exceeded

for dissolved lead or total or dissolved cadmium at any of the residences. The lack of cadmium, which is the more prevalent constituent at the Site, in the samples obtained from the residential wells and the inconsistent detection of lead in any residential well indicated that the wells had not been adversely affected by any impacted groundwater at the Site.

Radiological parameters were detected in only samples obtained from deep-zone wells during the Phase II evaluations, which led to the conclusion that the radiological parameters are naturally occurring and not related to former Site uses. With supporting data presented by O'Brien and Gere during the RI in 1990, it was concluded that there was no need to continue to address radiological parameters and they were eliminated from further evaluation.

The Phase I and Phase II Technical Memoranda concluded that, based on the groundwater data obtained, only lead and cadmium needed to be addressed as part of subsequent evaluations and remedial actions for groundwater at the Site. Therefore, the COCs for additional investigations were limited to lead and cadmium. VOCs (specifically chlorinated solvents and their degradation products) were also monitored even though they are not believed to require remediation. VOCs were determined to be naturally attenuating, as evidenced by lower concentrations relative to previous sampling events, and no active remediation for VOCs was deemed necessary. The data and results presented in the Phase I and Phase II Technical Memoranda are relevant to the selection of a remedial alternative for groundwater at the Site.

Following the completion of remedial activities for soil at the Site, the Group conducted groundwater sampling activities in January 2004 and April 2007 in accordance with EPA-approved work plans. The results of the post-RA groundwater sampling were presented in two reports entitled *Groundwater Monitoring Report* prepared by CSI in April 2004 and September 2007. Figures 4 and 5 depict the current and historical limits of groundwater impacted by concentrations of cadmium and lead exceeding applicable NJGWQSs, respectively. A summary of historical lead, cadmium, and VOC data for the monitoring wells at the Site is provided in Table 2. Figure 6 depicts the lead and cadmium concentrations in the groundwater from wells sampled during the April 2007 monitoring event, which is the most recent groundwater data obtained from the Site.

VOC analyses were also performed on the groundwater samples obtained by CSI in 2004 and 2007. As indicated above, the historical lead, cadmium, and total VOC data for the Site are presented in Table 2. An analysis of historical total VOC concentrations at the Site shows that the only significant concentrations of VOCs were detected at monitoring well 11 starting in 1989 (total VOC concentration of 5,124 µg/L). Additional VOC concentrations appeared at well BR in 1990 (total VOC concentration of 89.3 µg/L). Well BR is located in close proximity to monitoring well 11.

As of April 2007, the total VOC concentration at monitoring well 11 decreased to 5.86 µg/L (from 5,124 µg/L in 1989) and at well BR, the total VOC concentration decreased to non-detect (from 89.3 µg/L in 1990). Only one VOC was detected in the

groundwater sample from well 11 in April 2007 at a concentration that exceeds a New Jersey Groundwater Quality Standard (NJGWQS). Tetrachloroethene (PCE) in the sample from well 11 was detected at a concentration of 1.1 µg/L. The NJGWQS for PCE is 1 µg/L.

In addition, vinyl chloride was detected at low concentrations of 9.3 and 4.9 µg/L in the groundwater samples obtained during the April 2007 sampling event from wells MW-12 and MW-24, respectively. MW-12 and MW-24 are screened in the first confined aquifer. Both wells are located at the eastern and hydraulically up gradient edge of the Site, adjacent to the property used by the former Tomah Division of Exxon. VOCs are known to have been released by others into the environment at the former Tomah Division of Exxon property and are the likely sources of vinyl chloride at the Site.

Trace concentrations of hydrocarbon related compounds (ethylbenzene, toluene and xylenes) and chloroform have historically been detected at well SD. However, the April 2007 data indicated a total VOC concentration of 5.23 µg/L in the groundwater sample obtained from well SD. The detections of VOC compounds at well SD have declined to virtually non-detect levels.

The primary COCs for groundwater as defined by EPA on Table A of the 1994 ROD for the Site are: arsenic, beryllium, lead, 1,2-dichloroethane, 1,1-dichloroethylene, PCE and vinyl chloride. Based on the minimal VOC concentrations detected during intervening sampling events, as discussed above, VOCs in groundwater at the Site will continue to be monitored until a decision is made that no further sampling for VOCs is necessary. However, the presence of VOCs in groundwater is minor and unlikely to warrant remedial action. Arsenic and beryllium were eliminated from groundwater sampling at the Site, with the approval of the EPA, subsequent to the Phase I Technical Memorandum. Arsenic and beryllium were only detected in isolated areas and were thus not considered to be drivers for subsequent groundwater remedial actions. Therefore, the only remaining COC from the EPA list of COCs that may warrant remedial action is lead.

Cadmium, although not listed as a COC on Table A of the 1994 ROD, is included herein for evaluation purposes as it is the only constituent other than lead that continues to be present at concentrations in groundwater that warrants further consideration regarding potential remedial action. Therefore, the remainder of this FFS Report focuses on lead and cadmium in groundwater.

As mandated by the ROD, the RAOs for groundwater at the Site are to restore the impacted, unconfined aquifer to drinking water standards. Drinking water standards are defined as the most stringent of the New Jersey Maximum Contaminant Levels (NJMCLs), NJGWQSs, Practical Quantitation Limits (PQLs) or the Federal Maximum Contaminant Levels (MCLs). The drinking water standards are listed in Table F of the 1994 ROD (Appendix A). Completion of remedial activities for groundwater at the Site will need to include a demonstration that RAOs have been met for all constituents listed in Table F of the 1994 ROD (Appendix A).

→ How do we deal with this since MCLs have changed?

1.2.4 Contaminant Fate and Transport

Inorganics

The fate of lead and cadmium in groundwater is related to the pH of groundwater. As the pH levels in the central portion of the Site (particularly near wells OS, SS/SD and KS/KD) naturally increase to ambient levels, it is anticipated that lead and cadmium will be less soluble and undergo natural geochemical reactions including adsorption onto soil. Current and historic pH levels in groundwater are shown in Appendix D. The figures demonstrate gradual increases in pH levels in groundwater at the Site. The discussions that follow identify some of the factors that affect the rate and amount of lead and cadmium that will adsorb onto soil.

The presence of iron and manganese oxide/hydroxide coatings on soil particles in the subsurface at the Site were identified through detailed thin section petrography and bulk and clay X-ray diffraction performed by Core Laboratories and presented in the Phase II Technical Memorandum. The Core Laboratory report, included as Appendix B and described in the Phase II Technical Memorandum, provides supporting information related to the tendency of inorganic constituents like lead and cadmium to adsorb onto soil and thus have very limited mobility in the subsurface.

Soil samples obtained as part of the Phase II evaluation during the installation of monitoring wells 26, 28, and 29 from the water column near the top of the water table were used for the Core Laboratory analysis. The evaluation was conducted as recommended by the EPA's National Risk Management Research Laboratory following the review of the Phase I Technical Memorandum in 1998. The iron and manganese oxide/hydroxide coatings in the soil provide adsorption capacity for lead and cadmium that is anticipated to precipitate out of groundwater or otherwise adsorb onto soil or into soil coating at the Site.

The adsorption capacity of the aquifer materials at the Site was further identified through calculation of the cation exchange capacity (CEC) of the same soil samples analyzed by Core Laboratories, as described above. The CEC analysis was performed by Toxscan, Inc./Soil Control Lab and the data are included in Appendix C. The capacity of aquifer material to adsorb lead,⁴ for example, was determined to significantly exceed the amount required for the Site. The same is true of other inorganic constituents including cadmium. The transfer of lead and cadmium from groundwater to aquifer materials at the Site is desirable because it does not create any concerns regarding soil quality. For example, as stated in the Phase II Technical Memorandum *"if all of the lead detected in groundwater at the Site were sorbed onto aquifer material, then the resultant change in inorganic concentration in soil would be on the order of one to two ppm..... A similar relationship is true for cadmium."* With the decreased groundwater concentrations of

⁴ Aquifer adsorption capacity was estimated using the relationship identified in *Behavior of Lead in Soil* (Zimdahl and Skogerboe, 1977). For example, the aquifer material at the Site has the capacity to adsorb lead up to a concentration of 5,000 mg/kg, which exceeds by an extraordinarily large margin the amount required to achieve RAOs for groundwater.

lead and cadmium detected in 2007, the increase in lead and cadmium concentrations in soil resulting from adsorption, would be in the parts per billion to parts per million range. As discussed in Sections 3.2.2, 3.3.2, and 3.4.3, once adsorption to soil occurs lead and cadmium are virtually permanently removed from groundwater, barring some extreme, unforeseen circumstance like grossly acidifying the aquifer.

In addition to addressing the mechanisms which determine the fate of lead and cadmium, as described above in Section 1.2.3, several studies were conducted during the Phase II evaluation that also addressed the lack of mobility of lead and cadmium in groundwater. The initial step in assessing the mobility and thus the lack of transport of inorganic constituents by groundwater was to perform an aquifer test. A pumping well and an observation well were installed for testing purposes. The aquifer test included ambient water-level monitoring; a variable-rate pumping test (step test) and a 72-hour constant-rate pumping test (CRT) [GeoSyntec, 2000]. Throughout the course of the CRT, the pH and turbidity of the groundwater were monitored, and samples were collected for analysis of lead, cadmium, and general chemical parameters.

The analytical results from the aquifer test indicated that the concentrations of lead and cadmium declined during the course of the CRT to levels that are too low to effectively remove mass from the subsurface. Lead concentrations were below detectable levels at the conclusion of the CRT and cadmium concentrations steadily declined. It was estimated that the cadmium concentrations would have declined below detectable levels within 12 to 15 days of pumping, but not as a result of removing it from the subsurface, but only as a consequence of the inability to capture cadmium through groundwater extraction. Based upon these data, it was calculated that it would take between 50 and 60 years of aggressive pumping to remove a reasonable amount of the mass of the lead and cadmium from the Site by extracting groundwater. Additional discussion of the aquifer test is provided below and in Section 3.6.2 as part of the evaluation of the pump and treat remedial alternative.

The hydraulic parameters obtained during the performance of the aquifer test were subsequently used to prepare and refine a capture zone model for the Site. The capture zone model was developed as requested by the EPA for inclusion in the remedial design for groundwater at the Site. The capture zone model was created using MODFLOW [McDonald & Harbaugh, 1983]. The model was calibrated using data obtained through the aquifer test and data previously reported (e.g., Geraghty and Miller, 1983, O'Brien and Gere, 1990). The uppermost portion of the unconfined aquifer was modeled as it is the principally impacted zone. Several simulations were run after the model was calibrated. The most representative simulation indicated that pumping through well PW would capture the majority of the groundwater within the impacted area in less than one year. However, the ability to capture groundwater is entirely different from the ability to remove lead or cadmium, because they do not migrate appreciably with groundwater.

Subsequent to the capture zone modeling, the results were used to perform fate and transport modeling using MT3DMS. Using this model, two separate simulations

were performed for both lead and cadmium. The lead simulations reflected the 1983 to 1989 and 1989 to 1998 timeframes. The cadmium simulations reflected the beginning of 1989 to the end of 1989 and also 1989 to 1998. These simulations included pH values obtained during the 1983 and 1997 sampling events. Starting concentrations for lead were based upon the 1983 sampling results. Starting concentrations for cadmium were based upon the 1989 sampling results. The model predicted that lead and cadmium would not be significantly transported and that the adsorption of lead and cadmium to soil due to varying geochemical conditions as water from other areas was drawn into the impacted area rendered the inorganic constituents immobile. Simulated groundwater pumping from well PW resulted in no observable effect on the concentration or distribution of lead and cadmium. Subsequent groundwater data have verified that lead and cadmium are immobile as zones of impact have decreased, but not moved.

VOCs

As previously indicated, VOCs have historically been detected in wells 11, 12, BR, SD and 24 at the Site. The detections of vinyl chloride at wells 12 and 24 are believed to be related to impacts from a neighboring facility. The concentrations of vinyl chloride have decreased slowly since 1998 at these wells. A concentration of vinyl chloride of 13 µg/L was reported in well 12 in 1998 and was detected in 2007 at a concentration of 9.3 µg/L. Vinyl chloride is the end degradation product of PCE and remains fairly persistent in groundwater. Therefore, the trend of slowly declining concentrations of vinyl chloride at wells 12 and 24 is expected to continue. There is no evidence to suggest that the vinyl chloride is migrating beyond well 24.

During the 2007 sampling event, the VOCs previously detected in groundwater samples obtained from wells 11 and BR were not detected at well BR and had decreased to nearly undetectable concentrations at well 11. Detections of chloroform, ethylbenzene, toluene, and xylenes were found at well SD in 2007. The concentrations of these compounds were well below applicable NJGWQSs and these compounds are readily biodegradable. Therefore, the VOC concentrations at well SD are expected to naturally attenuate to below detectable limits in the near future. Therefore, although continued monitoring for VOCs should be conducted until the RAOs have been met; no remedial action is warranted for VOCs.

1.2.5 Baseline Risk Assessment

The unconfined aquifer at the Site is considered a Class II aquifer in the state of New Jersey. Groundwater in a Class II aquifer can theoretically be used for potable water with appropriate treatment. Currently, on-Site groundwater quality is inadequate for use as potable water. Therefore, the reasonably likely future-use scenarios for the Site will require at least temporary restrictions on the use of groundwater at the Site, thus mitigating the potential for human exposure.

A baseline risk assessment was conducted as part of the RI (O'Brien and Gere, 1990). It was conducted using COC concentrations from samples collected in 1989,

which contained much higher concentrations than are now present at the Site. Additionally, the baseline risk assessment includes a statement to the effect that the potential for future off-Site risks presented therein were overly conservative because the risk assessment considered on-Site groundwater concentrations in assessing off-Site risks.

Assessment of risk conducted as part of the Phase I and II Technical Memorandums [GeoSyntec, 1998 and 2000] was performed as a pathway analysis and it indicated: (i) no off-Site risks currently exist or will exist in the future, because there is no pathway between on-Site constituents and any possible off-Site receptors as the lead and cadmium were shown not to be migrating; and (ii) any possible exposure to constituents in groundwater can be prevented through the use of institutional controls.

Based on a lack of ^{current} off-Site risks due to a lack of pathways between on-Site groundwater containing COCs and off-Site locations, combined with the ability to restrict on-Site use of groundwater impacted by COCs, remedial action (other than institutional controls and monitoring) is not absolutely necessary. However, it may be desirable to speed the improvement of groundwater quality and shorten the period of time required for groundwater use restrictions by implementing remedial actions.

Can reasonably assume that pumping at an "off-site" location can draw contaminants from "on-site"

Has this been demonstrated?

baseline risk assessment evaluates risk in the absence of institutional controls.

2. IDENTIFICATION AND SCREENING OF TECHNOLOGIES

2.1 Overview

Groundwater sampling has been performed at the Site since 1983. Based on groundwater data collected during the RI, RD, and subsequent monitoring events performed in 2004 and 2007 after the soil remediation was completed (the data are summarized in Section 1.2.3 above), CSI and the Group in consultation with EPA representatives identified the five most viable groundwater alternatives for the Site. The remedial alternatives chosen for evaluation in this FFS include the following:

- No Action;
- Monitored Natural Attenuation (MNA);
- Reagent Injection;
- Permeable Reaction Barriers; and
- Pump and Treat.

These alternatives were presented to the EPA in a draft outline for this FFS in March 2007.

2.2 Remedial Action Objectives (RAOs)

RAOs are quantitative goals for reducing human health and environmental risks and/or meeting established regulatory requirements at the Site. Applicable or Relevant and Appropriate Requirements (ARARs) were used to define RAOs.

Based on current data and evaluations of potential risk, lead and cadmium in groundwater were identified as being the primary COCs. However, Table A of the 1994 ROD (EPA, 1994) for the Site lists arsenic, beryllium, lead, 1,1-dichloroethane (1,1-DCA), 1,1-dichloroethylene (1,1-DCE), PCE, and vinyl chloride (VC) as the COCs in groundwater. The Group considers cadmium to be a COC because of its presence in groundwater at concentrations that exceed applicable New Jersey drinking water standards. The primary risk to human health at the Site is through potential ingestion of affected groundwater as described in Section 1.2.5.

The RAO for groundwater at the Site as specified in the ROD [EPA, 1994] is "to restore the contaminated unconfined aquifer to drinking water standards for all contaminants" using ARARs. Therefore, after remedial actions for groundwater are completed, groundwater at the Site must contain Site-related contaminants at concentrations that are less than the most stringent of NJMCLs, NJGWQSSs, PQLs, or MCLs, as discussed above in Section 1.2.3. Table F from the ROD (EPA, 1994), which is included in Appendix A, details the extended list of constituents that may impact groundwater at the Site along with their applicable standards, the lowest of which is considered the RAO for that constituent.

*The FFS
should
incorporate
the updated
MCLs.*

For the purpose of selecting a remedy for the Site, the primary COCs of lead and cadmium will drive the remedy selection process. Although all RAOs must be met subsequent to the remedial action, this FFS focuses on lead and cadmium and the remedial alternatives that are best suited to remediate those constituents in groundwater. Accomplishing RAOs for lead and cadmium will also result in the achievement of RAOs for other COCs, as all of the COCs are subject to declining concentrations in groundwater by both natural attenuation and response to remedial activities. The RAOs for lead and cadmium are 5 µg/L and 4 µg/L, respectively.

The criteria used to evaluate achievement of the RAOs are based on NJGWQSS (NJAC 7:9C) for lead and cadmium. Groundwater with concentrations of lead and cadmium less than 5 µg/L and 4 µg/L, respectively, will be considered to have met all remediation requirements and achievement of the RAOs. The practical quantitation limit (PQL) is the lowest concentration that can be reliably detected by a laboratory during routine laboratory operating conditions as established by NJDEP as part of the NJGWQSSs. The PQL for lead is 5 µg/L and for cadmium it is 1 µg/L. Therefore, the RAOs for lead and cadmium are demonstrably attainable using standard laboratory methods. All other RAOs for groundwater will be addressed subsequent to remedy selection, implementation, and post-remediation groundwater monitoring.

2.2.1 Applicable or Relevant and Appropriate Requirements (ARARs)

ARARs can be divided into three general types. Chemical-specific ARARS set limits on concentrations of specific hazardous substances, pollutants and contaminants in the environment. Examples of these types of ARARs are drinking water standards and ambient water quality criteria. Location-specific ARARs set restrictions on certain activities based on their location (i.e. wetlands, floodplains, historic sites, etc). These ARARs generally apply to most alternatives as they are based on the location of the site. Finally, action-specific ARARs place restrictions on the technologies used for remedial action. The Resource Conservation and Recovery Act (RCRA) regulations for waste treatment, storage, and disposal are an example of such action-specific ARARs.

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria
- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

Potential Action Specific ARARs

Federal

- RCRA Groundwater Monitoring and Protection Standards (40 CFR 264, Subpart F)
- Clean Water Act – NPDES Permitting Requirements for Discharge of Treatment System Effluent (40 CFR 122-125)
- EPA Action Level for Lead in Drinking Water

New Jersey

- New Jersey Pollutant Discharge Elimination System Regulations (NJDES) and Effluent Limitations (NJAC 7:14A et seq)

Potential Location Specific ARARs

Federal

- Fish and Wildlife Coordination Act (16 USC 661 et seq.)
- National Environmental Policy Act (42 USC 4341 et seq.)
- Natural Historic Preservation Act
- Endangered Species Act
- Coastal Zone Management Act
- Farmland Protection Policy Act

New Jersey

- New Jersey Rules on Coastal Resources and Development (7:7E-1.1 et seq.)
- New Jersey Freshwater Wetlands Regulation

Based upon previous work conducted at the Site and the ROD, the most reasonable of the above ARARs is the NJGWQSs for lead (5 µg/L) and cadmium (4 µg/L). The other ARARs listed above are considered for all alternatives and are discussed where applicable below.

2.2.2 Development of Remedial Goals

The RAO for groundwater is to restore the groundwater in the unconfined aquifer to drinking water standards for all chemicals of concern as listed in Table F of the ROD [EPA, 1994], included in Appendix A. The FFS is focused on lead and cadmium in groundwater, because they are the only constituents that currently exceed an applicable standard that may reasonably be expected to continue to exceed standards for an extended period without remediation. Therefore, the remedial goal for this FFS is to achieve

*Development
of GW
cleaning
goals are
site specific*

concentrations of lead and cadmium in groundwater across the Site that are below 5 µg/L and 4 µg/L, respectively.

2.2.3 Amounts of Groundwater and COCs to be Remediated

There are approximately 25 million gallons of groundwater at the Site impacted by cadmium and 5.5 million gallons of groundwater impacted by lead at concentrations exceeding the NJGWQS. The impacted water is located in the main Site area as depicted on Figures 4 (cadmium) and 5 (lead). The volume of impacted groundwater was calculated using the most recent April 2007 groundwater data. The depth of impacted groundwater was conservatively estimated to be 40 feet and the areas impacted are shown in Figures 4 and 5, respectively.⁵ A porosity of 30% was used in the volume calculation.

Using the April 2007 data, CSI determined the current mass of lead remaining in groundwater at the Site to be approximately 1.2 pounds, and the approximate mass of cadmium remaining in groundwater at the Site is 6.2 pounds.

2.3 General Response Actions

General response actions are the broad categories of actions that may be taken to satisfy RAOs at a particular site. The following are the general response actions considered for this Site.

2.3.1 No Action

The no action alternative is required to be considered by the National Contingency Plan (NCP-40 CFR Part 300.430 [e][6]) to provide a baseline against which all other remedial actions can be compared. This remedial alternative would not change the status of the Site, and no actions would be taken to limit the potential for exposure to impacted groundwater at the Site.

2.3.2 Monitored Natural Attenuation

MNA is a response action for which no active remediation is performed. Rather, natural biochemical reactions are allowed to passively remediate groundwater. The constituents are immobilized through various natural conditions such as dilution, volatilization, adsorption, biodegradation, and chemical reactions with subsurface materials. These natural attenuation mechanisms can be modeled and predicted using various techniques. MNA includes groundwater monitoring to verify the rate of attenuation that is occurring.

⁵ The approximate area of lead impacted groundwater covers approximately 182,685 sq ft. The approximate area of cadmium impacted groundwater covers approximately 1,009,800 sq ft. See Figures 4 and 5 for the areas of impact.

2.3.3 In-situ Treatment

In-situ treatment is a response action that immobilizes or reduces the toxicity and/or volume of the constituents in groundwater without extraction. The action relies upon physical/chemical or biological means to alter the constituents in groundwater thus reducing their toxicity, mobility, or volume. This response action includes extensive groundwater monitoring to determine the effectiveness of the in-situ treatment method prescribed. The in-situ treatment methods considered in this FFS include reagent injection and permeable reaction barriers.

2.3.4 Collection/Extraction

Collection or extraction of groundwater typically involves pumping groundwater from collection trenches or wells. Through pumping of the groundwater, the mobility of the impacted water is reduced by changing the localized hydraulic gradient. An appropriate groundwater collection/extraction technology is dependent upon the type of constituents impacting groundwater, aquifer characteristics, depth of impacts, ability to extract the COCs from the aquifer using pumping techniques, and the remedial objectives. The collection/extraction technology is typically combined with treatment and discharge technologies.

2.3.5 Ex-situ Treatment

Ex-situ treatment response actions seek to reduce the mobility, toxicity, or volume of groundwater impacts through chemical, biological, or physical processes. Ex-situ treatment technologies are dependent on the ability to extract the COCs from the aquifer using pumping techniques. Treatment to reduce the toxicity or mobility of the COCs is then employed prior to discharge of the groundwater. Automated systems are typically employed to monitor the rate of extraction, apply the treatment technology, and monitor the effluent to ensure that impacted waters are not discharged inappropriately. Discharge technologies are employed to safely return the treated water to the environment.

2.3.6 Disposal/Discharge

Disposal/discharge technologies facilitate the safe return of treated water back to the environment. The disposal/discharge options typically include injection wells, discharge to publicly owned treatment works, discharge to surface water, discharge to recharge basins/infiltration galleries and discharge to public water systems. These methods are regulated through various effluent permits and require monitoring to ensure that treated waters meet applicable requirements.

The general response actions were used by the Group and CSI in developing potential remedial alternatives for the Site.

2.4 Identification and Screening of Technology Types and Process Options

The remedial action technologies discussed in this FFS were selected based on their ability to reduce the risk to human health and the environment from exposure to lead and cadmium in groundwater. Based on the limited potential for exposure, remediation technologies do not need to have an immediate endpoint to be effective. However, faster-acting technologies are favored to eliminate risk and cost effectively.

2.4.1 Identification and Screening of Technologies

The technologies identified for further consideration in this FFS have been identified through multiple studies as outlined in Section 1.2.3 above and with input from EPA representatives. Feasibility studies must include consideration of the no action alternative. Monitored natural attenuation (MNA) and reagent injection were recommended in the Phase II Technical Memorandum [GeoSyntec, 2000]. Groundwater pumping and treating was specified in the ROD and is therefore considered in this FFS. However, based on GeoSyntec's aquifer test performed in 1998 [GeoSyntec, 2000], the pump and treat alternative would ordinarily have been eliminated in the initial screening because of its lack of effectiveness. However, because it was the ROD selected remedy, a description of the pump and treat remedy and its evaluation is included in Section 3.6 for completeness. The remaining alternative to be considered is permeable reaction barriers (PRBs), which was recommended for consideration by EPA representatives.

2.4.2 Evaluation of Alternatives

The evaluation of remedial alternatives is discussed in detail in Section 3 and follows the format outlined in 40 CFR § 300.430(e) (7). Each technology was screened initially using three principle criteria: effectiveness, implementability, and cost. Each technology that was retained following initial screening is further evaluated in this FFS using nine additional criteria, which include:

Threshold Criteria

1. Overall Protection of Human Health and the Environment
2. Compliance with ARARs

Primary Balancing Criteria

3. Long-Term Effectiveness and Permanence
4. Reduction of Toxicity, Mobility, or Volume
5. Short-Term Effectiveness
6. Feasibility to Implement
7. Cost

Modifying Criteria

8. State/EPA Acceptance
9. Community Acceptance

3 EVALUATION OF ALTERNATIVES

3.1 Overview

In accordance with 40 CFR § 300.430(e) (7), the development of the remedial alternatives was guided by the following initial screening criteria:

- Effectiveness – the ability of an alternative to eliminate or reduce risks to human health and the environment by reducing toxicity, mobility, and/or volume in a reasonable period of time;
- Implementability – the capability of the alternative to be technically feasible given the availability of the technologies each alternative would employ; and
- Cost – the practicability of the alternative given the costs of construction and any long-term costs of operation and maintenance (O&M) activities.

The short- and long-term aspects of these factors were considered during the remedial alternative selection process. Alternatives deemed to be significantly less implementable or more costly than comparably effective alternatives were eliminated from consideration.

After the selection of remedial alternatives, each alternative was evaluated and compared using the nine evaluation criteria required by 40 CFR § 300.430(e)(9). A discussion of the criteria used to evaluate each alternative is provided below.

3.1.1 Threshold Criteria

Overall Protection of Human Health and the Environment

Alternatives were further evaluated based on their ability to protect human health and the environment in both the short- and long-term by eliminating, reducing, or controlling possible exposures to lead and cadmium in groundwater at concentrations exceeding RAOs.

Compliance with ARARs

The ability of alternatives to meet all applicable and relevant federal, state, and local environmental requirements (ARARs) was assessed for each alternative. The use of a waiver under 40 CFR § 300.430(f)(1)(ii)(C) was considered, where applicable.

3.1.2 Primary Balancing Criteria

Long-Term Effectiveness and Permanence

The long-term effectiveness of the alternatives was assessed along with the degree of certainty that the alternatives will prove successful. This was evaluated by considering the magnitude of constituents remaining in groundwater upon conclusion of remedial

activities and the adequacy and reliability of any control measures necessary to address constituents remaining in groundwater.

Reduction of Toxicity, Mobility, or Volume

The degree to which the alternative reduces toxicity, mobility, and/or volume was assessed. The factors considered include: the processes employed; the amount of constituents to be addressed; the degree of expected reduction of toxicity, mobility, and/or volume; the degree to which the treatment is irreversible or permanent; the type and quantities of any residual wastes, if any; and the degree to which remedy implementation reduces risks to human health or the environment.

Short-Term Effectiveness

The short-term impacts were evaluated based on the risks posed by the implementation of the alternative, including the potential impacts on workers, the community, and the environment during remedial activities, and the time until protection is achieved.

Feasibility to Implement

The ease or difficulty of implementing the alternative was considered. The factors impacting this consideration include: technical feasibility, including difficulties and unknowns; administrative feasibility, including coordination with all parties and the time involved in obtaining approvals and permits; and the availability of services and materials necessary to implement the alternative.

Cost

Costs were evaluated for each alternative. The costs included in the evaluation include capital costs, annual O&M costs and the net present value of capital and O&M costs.

3.1.3 Modifying Criteria

State/EPA Acceptance

State and/or EPA acceptance will be assessed upon receipt of comments to the FFS Report.

Community Acceptance

Anticipated community concerns were considered as part of the remedial alternative selection process, such as the timeframe required to meet RAOs, potential future uses of the Site, and the likelihood that implementation of the remedy would

impact the community (e.g. any discharges to the environment). The EPA will address community comments during the public review process.

3.2 No Action – Alternative 1

3.2.1 Description of No Action Alternative

The no action alternative involves no remedial action being taken specifically to address lead and cadmium in groundwater. Progress reporting as outlined in the ROD would continue to be applicable. However, no groundwater data would be obtained to monitor changes in groundwater quality or progression toward remedial goals. This alternative would involve institutional controls restricting the use and access to groundwater at the Site for as long as lead and cadmium concentrations in groundwater exceeded RAOs.

3.2.2 Evaluation of No Action Alternative

Threshold Criteria

Overall Protection of Human Health and the Environment

This alternative, although it does not include active remediation, would provide protection of human health and the environment based upon historical data that indicates that concentrations of lead and cadmium in groundwater are essentially immobile and are decreasing over time. Thus, the concentrations of lead and cadmium would eventually decline to RAOs. In the meantime, institutional controls would prevent access to impacted groundwater.

Compliance with ARARs

The following chemical-specific ARARs were identified for the no action alternative:

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria
- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

Action and location-specific ARARs do not apply to the no action alternative because it will not involve any discharge or impact to wetlands or Site features. The same is true for location-specific ARARs, because no action is taken for this alternative. The status of the location is not affected.

The most applicable and conservative ARAR for this alternative is the NJGWQS, which is consistent with the RAO described above. Review of historical data reveals that lead and cadmium concentrations are gradually declining in groundwater without active intervention.

The approximate rate of decrease in the lead and cadmium concentrations from groundwater derived from the data is approximately one order of magnitude in fifteen years. More detailed rate analysis is unavailable, because the frequency and regularity of groundwater sampling has been relatively low. By extrapolation, groundwater will likely meet RAOs within approximately 30 to 50 years under the no action scenario. It is important to note that the previous RAO for lead was 15 µg/L based upon the practical quantitation limit for lead analyses. Therefore, the reduction of the lead RAO to 5 µg/L from 15 µg/L has essentially tripled the estimated length of time required to achieve the RAO without active remediation..

Primary Balancing Criteria

Long-Term Effectiveness and Permanence

Based on the historical data, the reduction in concentrations of lead and cadmium under the no action scenario will be permanent barring significant acidification of the environment, such as could occur through unauthorized human-caused acid disposal on the Site, which could resolubilize some of the lead and cadmium that had adsorbed to native soils. However, the implementation of institutional controls restricting the access and such use of the Site will provide for a permanent remedy. Because lead and cadmium have been documented to be essentially immobile at the Site, there is no need for migration control and off-Site risks are not expected to occur.

Reduction of Toxicity, Mobility, or Volume

Based on the historical data showing decreasing concentrations of lead and cadmium in groundwater, reduction of toxicity and volume of contaminants could be achieved through the no action alternative. Over time, the lead and cadmium concentrations in groundwater are expected to decline to below detectable limits, thereby reducing both the toxicity and volume of contaminated groundwater. Because lead and cadmium are virtually immobile in groundwater, there is little concern regarding potential transport of lead and cadmium by groundwater at the Site.

The volume of impacted groundwater is expected to decrease in the future years. The volume of water impacted by lead at concentrations above the RAO in 1983 was more than 100 million gallons. There were no cadmium data obtained in 1983.

However, in 1988 cadmium was evaluated and approximately 83 million gallons of groundwater contained cadmium at concentrations above the RAO. Today, there are approximately 25 million gallons of groundwater impacted by cadmium and 5.5 million gallons of groundwater impacted by lead at concentrations exceeding applicable NJGWQSSs. The volume of groundwater affected by lead is less than 10% of the originally estimated volume and the volume of groundwater affected by cadmium is approximately 30% of the originally estimated volume.

In 1983, the approximate mass of lead in groundwater at the Site was 220 pounds. In 1988, the approximate mass of cadmium in groundwater at the Site was 70 pounds. Using the 2007 data, CSI calculated the current mass of lead remaining in groundwater at the Site to be approximately 1 pound and the approximate mass of cadmium remaining in groundwater at the Site to be approximately 6.4 pounds. Therefore, the remaining mass of lead in groundwater is currently estimated to be 0.5% of the 1983 estimate, and the remaining mass of cadmium in groundwater is estimated to be 9% of the 1988 estimate. Both the volume and mass calculations presented above demonstrate a dramatic reduction in the lead and cadmium in groundwater at the Site without active remediation of groundwater.

Short-Term Effectiveness

Based on reduced concentrations of lead and cadmium and the rate of groundwater improvement inferred from the above information (i.e. one order of magnitude in approximately 15 years), the no action alternative is estimated to require a period of 30 to 50 years to achieve the RAOs. Therefore, in the interim, institutional controls will be required to provide protection from impacted groundwater.

Feasibility to Implement

The no action alternative is not feasible to implement as it would not monitor the groundwater conditions at the Site and would thus not be protective of human health or the environment.

Cost

There are only nominal costs associated with the no action alternative. Minimal costs associated with administrative functions related to the ROD and institutional controls are required.

Modifying Criteria

State/EPA Acceptance

Based on the lack of monitoring and the estimated time period to attain the RAOs, the no action alternative will not likely satisfy state or EPA desires to return the Site to productive use as soon as possible. Without monitoring, which is not included in the no

action alternative, information will not be readily available regarding natural improvement in groundwater quality or any changing conditions.

Community Acceptance

The local community has expressed interest in a beneficial reuse of the Site. Therefore, it is assumed that the local community would prefer a remedy that at a minimum requires monitoring groundwater quality to determine achievement of RAOs and limited to no institutional controls restricting potential future uses of the Site.

3.3 Monitored Natural Attenuation (MNA)-Alternative 2

3.3.1 Description of MNA

The evaluations performed since the RI show that lead and cadmium are disappearing from groundwater at the Site without migrating to downgradient locations. The decline in the areas of impacted groundwater and concentrations of lead and cadmium are the result of natural attenuation, which is caused by naturally occurring geochemical and possibly biochemical reactions in the subsurface. Monitored natural attenuation is a viable remedy for groundwater at many sites and may be appropriate for this Site. EPA⁶ defines MNA as:

The reliance on natural attenuation processes to achieve Site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods.

Biochemical reactions, dispersion, dilution, and sorption processes that occur naturally in the subsurface are believed to be continually removing lead and cadmium from groundwater at the Site. MNA implementation at the Site would incorporate guidance from *Monitored Natural Attenuation of Inorganic Contaminants in Groundwater, Volumes I and II* (EPA, 2007) [MNA guidance document]. This document provides technical guidance for determining whether MNA is an effective approach for remediating groundwater impacted with inorganic constituents at a particular site.

The MNA guidance document (EPA, 2007) identifies a tiered analysis approach for reducing uncertainty in the remedy selection process while distributing costs to address four primary issues including:

1. Demonstration of active contaminant removal from groundwater and dissolved plume stability;
2. Determination of the mechanism and rate of attenuation;
3. Determination of the long-term capacity for attenuation and stability of immobilized contaminants; and

⁶ EPA's Office of Solid Waste and Emergency Response (OSWER) Directive titled "Use of MNA at Superfund, RCRA Corrective Action and Underground Storage Tank Sites" (Directive No. 9200.4-17p).

4. Design of a performance monitoring plan, including defining triggers for assessing MNA failure and establishing a contingency plan. (EPA, 2007)

Most of the technical evaluations which satisfy the tiered analysis approach outlined above were presented in the Phase II Technical Memorandum [GeoSyntec, 2000]. The technical evaluations performed in the Phase II Technical Memorandum were requested by members of the USEPA Office of Research and Development, National Risk Management Laboratory (USEPA Risk Management Lab) subsequent to review of the Phase I Technical Memorandum [GeoSyntec, 1998]. The recommendations made by the USEPA Risk Management Lab were designed to assess the on-going natural attenuation of constituents in groundwater at the Site.

The MNA alternative would also entail the implementation of institutional controls to limit access and potential use of impacted groundwater at the Site. This would protect human health and the environment until RAOs are achieved. The MNA alternative is evaluated in further detail in Section 3.3.2.

3.3.2 Evaluation of MNA

The following MNA evaluation was performed using the tiered analysis approach presented in the MNA guidance document [EPA, 2007] outlined above.

3.3.2.1 Demonstration of Active Contaminant Removal from Groundwater and Dissolved Constituent Stability

As shown on Figure 4 (cadmium) and Figure 5 (lead), the approximate area of impacted groundwater at the Site have decreased with time. There are no data to suggest that lead or cadmium have migrated in groundwater from the Site.⁷ Similarly, the data provided in Table 2 reveal generally decreasing concentrations of lead and cadmium in groundwater.

The historical groundwater data provided in Table 2 show that the concentrations of lead in groundwater have declined when compared to data obtained prior to 2004. The following exceptions to the declining concentration trends were noted, but they are not believed to be material evidence of contrary trends and instead are considered aberrant detections commensurate with the large area of the Site and long period through which it has been monitored.

- Data from three wells (34, ND, and NS) appear to be inconsistent with the favorable trend noted in the data. Total lead concentrations in groundwater samples from these three wells were apparently higher in 2007 than in 2004. However, when the

⁷ Groundwater migrates but does not appear to transport lead or cadmium to off-Site areas. Therefore, while groundwater in an area on the Site is affected by low pH values and contains total and dissolved concentrations of lead and cadmium, the lead and cadmium are not being transported with groundwater as it migrates. As a result, the impacted areas have remained stationary on Site and as a result of naturally occurring attenuative processes, the impacted areas have diminished in size.

groundwater samples from wells 34, ND, and NS were analyzed for dissolved lead, no dissolved lead was detected, indicating that the apparent concentrations of total lead are most likely related to turbidity and are not truly representative of groundwater quality.

- Groundwater samples obtained from wells OS, SS, and SD exhibited decreased total lead concentrations from 2004 to 2007. However, at these locations, where groundwater pH has historically been very low, the concentrations of dissolved lead compared to previous sampling events were apparently higher. At well SD, the dissolved lead was reported at a concentration higher than the total lead concentration, which is not possible as a true result. Therefore, the data for well SD are considered suspect.
- Monitoring wells OS, SS, and SD are located in the portion of the Site (near or downgradient from the former battery breaker where sulfuric acid is believed to have been released during battery recycling operations) which exhibits some of the lowest groundwater pH values. Monitoring well OS had the lowest reported groundwater pH in 2007. The dissolved lead concentrations at these locations are likely attributable to the acidic nature of the groundwater.

Other than these exceptions, the samples from the remaining twenty-three monitoring wells produced analytical results that showed that lead concentrations were stable, decreasing, or not detectable.

A review of the historical cadmium data provided in Table 2 also shows decreasing concentrations in samples obtained from all but two monitoring wells (23 and KDR) when compared to data obtained prior to 2004. The sample obtained from monitoring well 23 in 2007 showed a decreased concentration of total cadmium, but an increase in the dissolved cadmium concentration. The sample obtained from monitoring well KDR showed an increase in both total and dissolved cadmium concentrations in 2007. However, it is important to note that monitoring well KDR was replaced prior to the 2004 sampling event; thus, comparisons to historical data prior to 2004 for monitoring well KDR may be misleading, but show, as do the overwhelming weight of the remaining data, improvements in groundwater quality.

Groundwater samples obtained from other monitoring wells, such as 31, 33, JS and OS contained concentrations of cadmium that were flagged "J" estimated. Also, previous cadmium data from wells 31, 33, JS and OS were also flagged "J" estimated or "B" indicating blank contamination. Thus, it is not possible to perform a trend analysis of the estimated or qualified data for these wells. Therefore, with the two exceptions (23 and KDR) twenty-seven of the twenty-nine wells that were sampled exhibited decreasing, non-detectable, or similar cadmium concentrations in 2007.

For these reasons, it appears that lead and cadmium are effectively being removed from groundwater without active remediation by natural attenuation processes. Therefore, MNA is believed to be a viable remedy for the Site.

3.3.2.2 Determination of the Mechanism and Rate of Attenuation

Studies have been conducted at various sites to evaluate the mechanisms and the rate of attenuation of metals in groundwater. For example, Yong et al [1993] determined that:

"At high soil solution pH values, retention of heavy metals by precipitation mechanisms prevails, whereas at low soil solution pH, retention by cation exchange mechanisms becomes dominant."

A study of the CEC of the soil at the Site revealed that the soil has the capacity to adsorb the lead and cadmium present in groundwater at the Site. As discussed in Section 1.2.4, the adsorption capacity of the aquifer materials at the Site was evaluated as part of the Phase II evaluation, and the results of the CEC analysis are included in Appendix C. As also stated in Section 1.2.4, the capacity of aquifer material to absorb lead is more than sufficient at the Site for groundwater remediation purposes.

Much of the natural attenuation of lead and cadmium occurs through cation exchange. In areas where the groundwater and soil pH equilibrates to a higher pH over time, precipitation is also effective. The presence of iron and manganese oxide/hydroxide coatings on soil particles in the subsurface at the Site were identified as described in Section 1.2.4 and Appendix B. The iron and manganese oxide/hydroxide coatings provide adsorption sites in the soil for lead and cadmium.

Previous studies have shown that the soil at the Site has the CEC and requisite iron/manganese soil coatings to adsorb the constituents present in groundwater at the Site. Data showing the disappearance (e.g., declining concentrations) of lead and cadmium from groundwater is evidence of the attenuative capacity of the subsurface of the Site. The rate of attenuation of these constituents is estimated as the approximate rate of disappearance of lead and cadmium from groundwater. Based on the data obtained to date, the rate is approximately one order of magnitude in fifteen years. By extrapolation, groundwater will likely meet RAOs within approximately 30 to 50 years under the no action scenario. The same is true for the MNA alternative.

It is important to note that the previous RAO for lead was 15 µg/L based upon the practical quantitation limit for lead analyses. Therefore, the reduction of the lead RAO to 5 µg/L from 15 µg/L has significantly increased the length of time required to achieve the RAO under the no action or MNA alternatives.

3.3.2.3 Determination of the Long-Term Capacity for Attenuation and Stability of Immobilized Contaminants

The results of the Phase II evaluation documented that the soil has more than enough capacity to adsorb the remaining lead and cadmium present in groundwater at the Site. The stability of the immobilized constituents is directly related to the pH of groundwater at the Site and the geochemical reactions that occur. Included in the Core

Laboratory report provided in Appendix B is a sequential extraction analysis. This analysis used sequentially more acidic solutions to extract cadmium and lead from the soil samples provided. The study concluded that a solution with a pH of less than 2 was needed to extract cadmium and lead from the soil samples at detectable concentrations. The study verifies that after adsorption of lead and cadmium onto native soils, it would be reasonably permanent because conditions causing an ambient groundwater pH of 2 or less are very unlikely to occur at the Site. In fact, envisioning a condition that would cause pH values of groundwater at the Site to reduce to pH 2 or less requires envisioning a catastrophic and unforeseeable occurrence. Institutional controls would need to be in place to prevent persons from drinking groundwater until RAOs are achieved.

3.3.2.4 Performance Monitoring Plan

MNA for the Site would initially entail quarterly groundwater monitoring for total and dissolved lead and cadmium as well as other required MNA water quality parameters (i.e. chloride, nitrate, sulfate, ferrous iron and total alkalinity) at the wells identified in Table 3. The existing monitoring well network would be enhanced by the addition of two monitoring wells to provide additional data along the western perimeter of the Site, as shown on Figure 7. Figure 7 also depicts the locations of the proposed existing and new monitoring wells to be sampled. With the addition of the two new monitoring locations, the monitoring well network will meet the MNA criterion for a monitoring well network outlined in the *Use of MNA at Superfund, RCRA Corrective Action and Underground Storage Tank Sites* guidance document produced by the EPA in 1999. The criterion outlined in this EPA guidance [EPA, 1999] includes:

- The ability to verify that the impacted zones of groundwater are not expanding (either downgradient, vertically or laterally);
- The ability to verify no unacceptable impact to downgradient receptors;
- Demonstrate that natural attenuation is occurring according to expectations;
- Identify any toxic and/or mobile transformation products;
- Detect changes in environmental conditions (i.e. hydrogeologic, geochemical, microbiological or other changes) that may reduce the efficacy of natural attenuation process;
- Detect new releases of chemicals to the environment that could impact the effectiveness of the natural attenuation remedy;
- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors; and
- Verify attainment of remediation objectives.

Sampling would be conducted as defined in CSI's *Groundwater Monitoring Plan for the NL Industries Superfund Site* [CSI, 2006] to provide the data needed to evaluate MNA. The plan outlines sampling methods and quality assurance procedures to be performed. The plan would be modified to include additional analyses required to satisfy the MNA criterion (i.e. by adding sulfate, nitrate, chloride). A letter report documenting the results of each quarterly sampling event would be provided to the EPA following

each event. At the end of one calendar year of sampling, recommendations would be made to modify the sampling program based upon the data obtained.

3.3.2.5 Proposed Triggers for Determining MNA Failure or Success

The anticipated triggers for determining failure of the MNA remedy at the Site would be the confirmed detection of lead and/or cadmium at a location where no detections were previously reported and/or an order of magnitude increase in concentration of any COC at any well. The MNA remedy would be considered a success provided the concentrations of the COCs trend downward over time such that even with some perturbations and variations in COC concentrations and trends, the weight of evidence indicates improving groundwater quality. MNA would be considered complete when all sampled wells contained no COCs above the RAOs for the Site as outlined in Table F of the ROD [EPA, 1994] included in Appendix A.

3.3.2.6 MNA Contingency Plan

Should the MNA remedy show failing results, a contingency plan should include the evaluation of failure, which may include additional sampling and analyses and/or the installation and sampling of additional wells. If necessary, a more active remedial alternative such as reagent injection, as discussed herein, may need to be initiated. The implementation of the proposed alternative remedy would be addressed in a work plan submitted to EPA for approval.

Threshold Criteria

Overall Protection of Human Health and the Environment

The MNA alternative, coupled with institutional controls restricting access to and use of groundwater in the unconfined aquifer in the affected area of the Site, would be protective of overall human health and the environment. By restricting access and by restricting use of the impacted groundwater, human health will be protected. The limited mobility of lead and cadmium in groundwater at the Site will ensure that impacted groundwater does not migrate from the Site. Long-term groundwater monitoring would be performed as part of efforts to ensure the effectiveness of the remedy.

Compliance with ARARs

The ARARs identified for this alternative include the following chemical-specific ARARs; location and action-specific ARARs do not apply to this alternative:

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria

- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

The most applicable and conservative ARAR for this alternative is the NJGWQS, which is consistent with the RAOs described above. Similar to the no action alternative, groundwater is estimated to meet RAOs within approximately 30 to 50 years under the MNA scenario. The groundwater monitoring program will provide ample opportunities to document effectiveness (i.e. RAO attainment) and any changes that may occur in groundwater.

Primary Balancing Criteria

Long-Term Effectiveness and Permanence

The long-term effectiveness and permanence of this remedy are excellent. As demonstrated by the historical data provided in Table 2 and illustrated in Figures 4 and 5, lead and cadmium are relatively immobile in groundwater at the Site. As the pH levels in the central portion of the Site (particularly near wells OS and KS/KD) increase over time, lead and cadmium are expected to continue to adsorb onto soil particles. Iron and manganese oxide/hydroxide coatings on soil particles at the Site provide adsorption sites and capacity. The aquifer materials contain more than sufficient capacity to adsorb the amount of lead and cadmium present in groundwater at the Site, without adverse impact in soil. The transfer of lead and cadmium from groundwater to aquifer materials at the Site is desirable and permanent provided that substantial acidification of the soil and groundwater (e.g. reduction of pH to less than 3) by human activity does not occur in the future.

Reduction of Toxicity, Mobility, or Volume

As indicated, it is anticipated that RAOs will be achieved within 30 to 50 years. Toxicity, mobility, and the volume of lead and cadmium-impacted groundwater will steadily decline to insignificant levels in the same period.

The limited mobility of lead and cadmium in groundwater has been documented through historical groundwater monitoring (the data are provided in Table 2 and are shown in Figures 4 and 5). These data demonstrate that the area of impacted groundwater containing elevated concentrations of lead and cadmium has remained generally in the same location but has decreased in volume since 1983.

The volume of impacted groundwater has declined considerably since the 1980s. The current mass of lead remaining in groundwater at the Site was calculated to be 0.5% of the mass in 1983. The current mass of cadmium in groundwater at the Site was

calculated to be 9% of the 1988 mass. Therefore, the volume of contaminated groundwater at the Site has reduced dramatically in little more than 20 years without active remediation efforts.

Short-Term Effectiveness

The MNA alternative is estimated to require a period of approximately 30 to 50 years to achieve the RAOs. Therefore, in the interim, monitoring and institutional controls will be required to provide protection of human health and the environment.

Feasibility to Implement

The feasibility for implementation of this remedy is excellent. The procedures for performing the required groundwater monitoring are already in place with approved groundwater monitoring and quality assurance plans [CSI, 2006]. Installation of additional monitoring wells to satisfy EPA's MNA monitoring well network criterion can be accomplished through the use of a New Jersey licensed well driller. The implementation of institutional controls is also feasible. There are no foreseeable technical obstacles to prevent implementation of the MNA alternative.

Cost

CSI has developed a cost estimate to perform MNA at the Site, which is presented in Tables 4 and 5. Table 4 presents the cost for performing one round of groundwater monitoring at the wells identified in Table 3. Samples will be analyzed for total and dissolved lead and cadmium and VOCs as well as the required MNA water quality parameters (i.e. chloride, nitrate, sulfate, ferrous iron, and total alkalinity). Table 5 includes the present worth cost of a thirty-year monitoring program.

For purposes of the cost estimate, the monitoring program is assumed to require two years of quarterly sampling, three years of semi-annual sampling and twenty-five years of annual sampling. The monitoring frequency would be adjusted based on the data obtained, however these assumptions were used to develop the cost estimate provided in Table 5. A present worth of \$1,113,537 is estimated for a thirty-year monitoring period using the above assumptions. As discussed above in Section 3.3.1, CSI recommends the installation of two additional wells at the Site for adequate monitoring of the western perimeter. This would entail an additional one-time cost of approximately \$20,000.

Modifying Criteria

State/EPA Acceptance

The MNA remedy for inorganics is becoming more commonly accepted by the regulatory community as the technical evidence for natural attenuation processes are being developed. MNA has long been deemed an acceptable remedial alternative at sites where organic constituents are the concern. The issuance of the final EPA guidance

document for MNA at sites with inorganic constituents in groundwater [EPA, 2007] will further advance the acceptance by the regulatory community towards the MNA remedy for inorganics in groundwater. It is anticipated that State and EPA acceptance for this remedial alternative can be obtained, particularly since on-Site use of shallow groundwater is unnecessary for foreseeable future Site uses.

Community Acceptance

The lack of intrusive work involved with this alternative, combined with the protection of human health and the environment through leaving impacted groundwater in place, is expected to be a benefit with the local community. However, the implementation of institutional controls on the property, thereby possibly limiting some potential future uses of the Site, may not be favored by the local community.

3.4 Reagent Injection – Alternative 3

3.4.1 Description of Reagent Injection

Reagent injection involves the introduction of a reagent into the water table aquifer using existing monitoring wells and/or injection wells or well points to be installed at a later date. The reagent applied will be selected based upon the results of a bench scale treatability study (BSTS) and a field pilot study. Preliminarily, the results of a BSTS reveal that phosphate reagents will be highly effective for both lead and cadmium in groundwater. The use of phosphates for treating lead impacted soils and waters has been widely used to immobilize inorganic constituents including lead. A field scale study, to be conducted at a later date, should be used to confirm effectiveness at this Site and assist in calculating parameters required for successful remediation (i.e. number of well points, spacing, etc).

The reagent injection technique is based on the fact that metals dissolved or entrained in groundwater may be immobilized by adsorption onto a substrate (i.e. the native soil) and/or by incorporating the metal into a molecular structure (intercalation) which may then adsorb or become incorporated into soil as a complex or precipitate [Water Remediation Technologies (WRT), 2007]. The injection of alkalinity provides pH management to reduce the solubility of inorganic COCs, promote well-documented adsorption and precipitation reactions between metals and natural or injected reagents, and immobilize metals in the subsurface. Prior to the injection of reagents, sodium hydroxide will be used to increase the pH of the groundwater in localized areas to promote subsequent removal of lead and cadmium from groundwater when the reagent is injected.

The locations at which the pH adjustment and reagent injection will occur will be determined based upon the results of a pilot study and subsequent groundwater monitoring. However, some proposed locations for reagent injection will most likely include areas surrounding monitoring wells OS, KDR, KDS, SS, and SD. CSI envisions installing a well point grid in these areas for performing the reagent injections. A conceptual representation of the reagent injection process is presented on Figure 8.

The effectiveness of the reagent injection alternative would be assessed by periodic groundwater sampling and analysis. For cost estimating purposes, it is assumed that quarterly sampling will be performed initially, followed by semi-annual and annual sampling. The monitoring frequency will be modified based upon the data obtained during the pilot study and initial post-reagent injection monitoring events. The groundwater monitoring program would be similar to the program outlined above for the MNA remedy.

3.4.2 Evaluation of Reagent Injection

Groundwater samples were obtained from wells JDR, JS, KDR, KSR, NS, OS, SD, SS, 11, 23, 31, and 34 and analyzed for dissolved iron, total iron, alkalinity, hardness, BOD, COD, chlorides, and sulfate in April 2007. The analytical data from these samples, summarized on Table 6, along with the results from a bench scale treatability study (BSTS) were used to evaluate the reagent injection alternative.

3.4.3 Bench Scale Treatability Study

CSI retained WRT to perform a BSTS on samples of groundwater obtained from the Site. The purpose of the BSTS was to preliminarily identify reagents that effectively cause a decrease in lead and cadmium concentrations in the water samples and to tentatively estimate dosing requirements for field application. Based upon WRT's experience and expertise with treating inorganics in groundwater, the reagents tested were limited to phosphates and sulfates. These reagents are the most technically viable for the treatment of lead and cadmium in groundwater.

CSI obtained 5-gallon samples of groundwater from four representative wells (OS, SS, SD, and KDR). The well locations were chosen based on the results of the April 2007 groundwater monitoring event. Monitoring wells containing the highest concentrations of lead and cadmium from the Site were chosen. The aliquots of groundwater were sent to WRT to perform a BSTS. WRT performed the BSTS using the following procedures:

- Separated aliquots of groundwater into multiple beakers;
- Added a known amount of a single reagent into each beaker and stirred using gang stirrer or similar device at low revolutions per minute (<50);
- Monitored the formation of any precipitates;
- Filtered the supernatant and analyzed the supernatant for lead and cadmium using EPA Method 200.8;
- Evaluated results and varied reagent addition, as necessary.

WRT's report containing the BSTS results is provided in Appendix E. The following is a summary of the main findings of the BSTS:

- The three reagents tested were organosulfur (Test A), organosulfur with pH adjustment (Test B) and sodium polyphosphate (Test C);

- All three reagents were effective in reducing lead and cadmium concentrations in the samples provided;
- Organosulfur with pH adjustment (Test B) and sodium polyphosphate (Test C) both reduced lead and cadmium concentrations to below detectable limits for all four sample aliquots;
- The cost for treatment of 1000 gallons of water using sodium polyphosphate is dramatically less than using organosulfur with pH adjustment.

In summary, the BSTS was successful in demonstrating that reagent injection using sodium polyphosphate is a cost effective and viable remedial alternative for this Site.

Threshold Criteria

Overall Protection of Human Health and the Environment

The reagent injection alternative will effectively protect overall human health and the environment from the risks associated with elevated lead and cadmium concentrations in groundwater at the Site by more rapidly and permanently reducing the concentrations of lead and cadmium in groundwater. The remedy has the potential to more quickly bring the concentrations of lead and cadmium in groundwater to below applicable NJGWQSs, therefore eliminating any potential risk to human health and the environment from impacted groundwater at the Site. Sodium polyphosphate is relatively non-toxic in nature and is relatively easy to handle.

Compliance with ARARs

The following ARARs have been determined to be potentially applicable to this alternative:

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria
- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

Potential Action Specific ARARs

Federal

- RCRA Groundwater Monitoring and Protection Standards (40 CFR 264, Subpart F)
- EPA Action Level for Lead in Drinking Water

Potential Location Specific ARARs

Federal

- Fish and Wildlife Coordination Act (16 USC 661 et seq.)
- National Environmental Policy Act (42 USC 4341 et seq.)
- Endangered Species Act
- Coastal Zone Management Act
- Farmland Protection Policy Act

New Jersey

- New Jersey Rules on Coastal Resources and Development (7:7E-1.1 et seq.)
- New Jersey Freshwater Wetlands Regulation

The reagent injection alternative is compliant with all ARARs. It is believed that NJGWQSs can be met for groundwater at the Site, based on the BSTS results, in less than ten years using this remedial alternative, therefore achieving all ARARs considered for this Site. This estimated timeframe for achieving ARARs can be further refined by conducting a field scale pilot study. The use of the reagents in groundwater are not anticipated to affect any other applicable chemical or location specific ARARs, however groundwater monitoring would be performed to ensure that no other criteria are exceeded.

Primary Balancing Criteria

Long-Term Effectiveness and Permanence

The preferred reagent injection technology is to permanently remove cadmium and lead from solution by precipitating them as metal phosphates. This removes the contaminants from solution and provides groundwater that meets or exceeds the RAOs.

The metals are incorporated into a crystalline lattice using the phosphate precipitation process. The crystalline lattice consists of calcium phosphate and either lead or cadmium phosphate. Metal phosphates are highly insoluble [Nriagu, 1984] and, it has been suggested, their low solubility renders metals in metal phosphates non-bioavailable [e.g. Ma *et al.*, 1993; Cotter-Howells and Caporn, 1996]. Over the long-

term, it is anticipated that the pH levels in groundwater at the Site will equilibrate to ambient levels, typically between pH 5 and 6. The ambient pH will not cause any significant resolubilization of lead or cadmium after the metals have reacted to form metal phosphate compounds and/or they have adsorbed to native soils. Only extraordinary circumstances, such as unauthorized acid disposal onto the ground surface at the Site, could potentially cause the pH of groundwater to become acidic enough to resolubilize the cadmium and lead.

Included in the Core Laboratory report provided in Appendix B are the results of a sequential extraction analysis performed on soils from the Site. This analysis used sequentially more acidic solutions to extract cadmium and lead from the soil samples that were tested. The study concluded that a solution with a pH of less than 2 was needed to extract cadmium and lead from the soil samples at detectable concentrations. The study verified that after adsorption of lead and cadmium onto native soils, it would be unlikely that the metals would resolubilize. The phosphate precipitates also formed through reagent injection would be of comparable solubility and thus the intercalation of cadmium and lead in these precipitates may be regarded as permanent. Therefore, the long-term effectiveness and permanence of the reagent injection alternative are excellent.

Reduction of Toxicity, Mobility, or Volume

The formation of metal phosphates is known to remove cadmium and lead from solution and is used to treat groundwater to meet the RAOs. The metals are adsorbed onto native soils or incorporated into metal phosphate compounds using the reagent injection process. Precipitation and adsorption is done in-situ, so there are no wastes produced through this treatment process.

The volume of impacted groundwater is expected to continue decreasing as is evident though analysis of historical data provided in Table 2 and Figures 4 and 5. The volume of impacted groundwater at the Site is approximately 25 million gallons. Reagent injection is anticipated to increase the rate of reduction in volume of impacted water. It is anticipated with reagent injection that the volume of contaminated groundwater can be reduced to approximately zero in less than 10 years using reagent injection (compared to 30 – 50 years without active remediation). The low concentrations of VOCs currently present at the Site will continue to degrade naturally after implementation of the reagent injection alternative. The reagent injection alternative is not anticipated to adversely affect VOC concentrations.

Short-Term Effectiveness

Reaction rates are rapid and removal of lead and cadmium from solution is accomplished within minutes of promoting the reaction. Based upon the low concentrations of lead and cadmium measured in groundwater at the Site during the April 2007 groundwater monitoring event, it is believed that RAOs can be met in less than ten years using this remedial alternative.

Feasibility to Implement

The technology is simple and easy to implement. The reagents are safe and can be applied with standard personal protective equipment. The reagents can be injected relatively easily into the shallow, sandy Site subsurface using a Geoprobe™ to install well points and the reagent can be pumped or poured into the well points from small containers. Reagents are relatively inexpensive and readily available.

Cost

Costs for the sodium polyphosphate reagents as estimated in the BSTS [WRT, 2007] are between \$1 and \$9 per 1000 gallons treated (a median cost of \$5 was used for this cost estimate). The actual cost is contingent upon the number of injections required to treat the 25 million gallons of impacted groundwater at the Site. CSI assumed that four injections over the course of one year will be sufficient to achieve RAOs for lead and cadmium in groundwater at the Site. This estimate can be refined after field scale studies are conducted. It will also be necessary to adjust the pH of the impacted groundwater to be higher than 3 and preferably to between 8 and 9. The volume of sodium hydroxide (NaOH) required to adjust twenty-five million gallons of water from a pH of 3 to 4 to between 8 and 9 is approximately 5,000 pounds. Table 7 provides an estimate for performing the four reagent injections and pH adjustment. Table 8 provides a present worth cost calculation for performing this work. The present worth cost for performing the reagent injection alternative as described above is approximately \$882,325.

The costs for performing associated groundwater monitoring activities are not included in Tables 7 and 8. However, based on the scope for the MNA remedial alternative described above and using a monitoring period of ten years (estimated to be two years of quarterly monitoring, three years of semi-annual monitoring, and five years of annual monitoring), the cost for performing groundwater monitoring is approximately \$650,000. Monitoring frequencies will be adjusted based upon the pilot study and post-reagent injection sampling results.

Modifying Criteria

A pilot study is necessary to estimate costs and determine the radius of effective reagent distribution (radius of influence) and the number of times injection will be required. The subsurface pH must be adjusted into the alkaline range (8-9) prior to injecting phosphate reagent. Excessive subsurface acidity could increase consumption of alkali and increase cost. However, initial treatability study data presented in Table 6 indicates nominal acidity levels therefore it is unlikely that alkali costs would increase.

State/EPA Acceptance

Metal phosphate precipitation has been employed at numerous sites for in-situ removal of toxic metals from solution. The technology is recognized as effective by EPA.

Community Acceptance

No objections are anticipated as the reagents are safe and NSF (National Sanitation Foundation) approved for drinking water contact. The reagent injection alternative also has the added benefit of requiring institutional controls for shorter periods of time when compared to other potential remedies.

3.5 Permeable Reaction Barrier – Alternative 4

3.5.1 Description of Permeable Reaction Barrier

A permeable reaction barrier (PRB) is composed of a trench filled with a reactive substance that reacts with and removes metals, in this case cadmium and lead, from solution as the groundwater containing lead and cadmium passes through the barrier. The PRB can be a continuous barrier or it can be constructed using the funnel and gate concept. In the funnel and gate, a predominately impermeable material is used to form a curtain or barrier wall (funnel) to channel groundwater into a PRB (gate). The PRB is an underground vault containing reactive material. Theoretically, impacted groundwater is directed through the PRB where it is treated. However, to be effective, the constituents in groundwater must be sufficiently mobile to be transportable by groundwater into the PRB otherwise no treatment is achieved. A cross-section of an example PRB is shown as Figure 9. A possible location for a PRB at the Site is shown in Figure 10.

At the Site, the PRB would be constructed using calcium hydroxyapatite (e.g. seashells or fish bones). Theoretically, metals are incorporated into the hydroxyapatite-based minerals through chemical reactions. The reactions are the same as or similar to those involved in the injection of phosphates discussed above in Section 3.4 under the reagent injection alternative. The actual effectiveness of the PRB at the Site would depend upon the mobility of lead and cadmium in groundwater, which has been documented to be low, if not zero (Figures 4 and 5).

3.5.2 Evaluation of Permeable Reaction Barrier

PRBs may be constructed using a variety of reactive materials. Recent studies have shown Apatite II™ to be effective for the removal of lead and cadmium from runoff from mine tailings. EPA and the Idaho Department of Environmental Quality (IDEQ) demonstrated the feasibility of PRBs at the Success and the Nevada Stewart Mines in Idaho. In these studies, the investigators dealt with runoff from mine tailings. The runoff contained lead, cadmium, and zinc. Unlike groundwater at the Site, the runoff from the

mine tailings readily transported dissolved lead, cadmium, and zinc such that it was readily directed to flow through the PRB.

Apatite II™ is “a special form of biogenic apatite” that is highly reactive [Wright and Conca, 2002]. Metal-phosphates, which form from the reactions of metals like lead and cadmium, are highly insoluble minerals and are the same minerals formed in the BSTS performed for the reagent injection alternative discussed above in Section 3.4. Reacting lead and cadmium with phosphates will cause them to precipitate and adsorb out of the water column.

The Success Mine PRB reduced the concentrations of lead, cadmium, and zinc that flowed through the PRB. However, the reactive media was prone to clogging. Several techniques were used to limit clogging with varying degrees of success including mixing gravel or plastic packing rings with the medium and injecting air. Similar results were reported for the Nevada Stewart Mine Site [MSE Technology Applications Inc, 2007]. Copies of the papers reviewed for the case studies described above are attached as Appendix F.

It is important to note that both case studies discussed above were located in areas where the impacted water flowing out of tailings piles could readily be diverted through the PRBs. Conditions at the Site are not favorable for PRB use. The unconfined aquifer at the Site ranges in depth from 20 to 40 feet bgs [GeoSyntec, 2000] which would require deep construction, the affected area at the Site is relatively large, and the hydraulic gradient at the Site is low. Moreover, and fatal to the concept, is that lead and cadmium are not significantly migrating in groundwater at the Site. Therefore, relatively unimpacted groundwater only will pass through the PRB leaving the affected area untreated.

Threshold Criteria

Overall Protection of Human Health and the Environment

The limited mobility of lead and cadmium in groundwater at the Site will prevent significant volumes of impacted groundwater from entering the PRB. While groundwater may be diverted into it, it is not likely that significant amounts of lead or cadmium will be transported into the PRB. Therefore, concentrations of lead and cadmium in groundwater will remain untreated, providing no additional protection of human health and the environment than provided either by no-action or MNA.

Compliance with ARARs

The following ARARs have been determined to be potentially applicable to this alternative:

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria
- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

Potential Action Specific ARARs

Federal

- RCRA Groundwater Monitoring and Protection Standards (40 CFR 264, Subpart F)
- Clean Water Act – NPDES Permitting Requirements for Discharge of Treatment System Effluent (40 CFR 122-125)
- EPA Action Level for Lead in Drinking Water

New Jersey

- New Jersey Pollutant Discharge Elimination System Regulations (NJPDES) and Effluent Limitations (NJAC 7:14A et seq)

Potential Location Specific ARARs

Federal

- Fish and Wildlife Coordination Act (16 USC 661 et seq.)
- National Environmental Policy Act (42 USC 4341 et seq.)
- Endangered Species Act
- Coastal Zone Management Act
- Farmland Protection Policy Act

New Jersey

- New Jersey Rules on Coastal Resources and Development (7:7E-1.1 et seq.)
- New Jersey Freshwater Wetlands Regulation

Concentrations of lead and cadmium in groundwater will not be significantly reduced by the PRB. Attainment of ARARs will depend solely upon the continued decline in lead and cadmium concentrations in groundwater without active remediation,

as described for the no action and MNA alternatives. Additional action-specific ARARs would need to be considered for this remedy, such as the Clean Water Act NPDES permitting requirements and NJPDES effluent limitations, for the discharge of treated water. These ARARs would require additional monitoring and permitting activities not associated with other remedial alternatives, except the pump and treat alternative described in Section 3.6 below.

Primary Balancing Criteria

Long-term Effectiveness and Permanence

As with calcium phosphate precipitation that is part of the reagent injection alternative, the groundwater reactions, when they occur, are essentially irreversible under all, but extraordinary conditions (e.g. future anthropogenic acidification of the area). The active material in the PRB has a finite capacity to remove metals from water. Clogged media would require corrective action to promote water passage or replacement. Also, spent media would need to be replaced periodically. Replacing and unclogging media generates waste that would require off-Site disposal.

Reduction of Toxicity, Mobility, or Volume

The metals (lead and cadmium) in the groundwater would be removed to concentration at below NJGWQSSs, and fixed (immobilized) if the metals can be transported into the PRB. Spent reactive media may eventually need to be removed and disposed. However, the mobility of the contaminants in groundwater at the Site has been demonstrated to be minimal. Therefore, the volume of impacted groundwater will not be reduced by the PRB. Therefore, the affected area will remain untreated.

Short-Term Effectiveness

No treatment, or very limited treatment, of impacted groundwater is expected at the Site from the use of a PRB, because the metals will not migrate with groundwater into the PRB.

Feasibility to Implement

A PRB could be constructed at the Site using a variety of trenching and excavation techniques. However, the configuration of the Site presents several construction challenges (i.e. railroad tracks, wetlands, and streams). Figure 10 depicts a possible location for a PRB funnel and gate at the Site. Because the locations of the highest concentrations of lead and cadmium in the groundwater at the Site are found near the Conrail railroad tracks at locations OS and KDR, the PRB would need to be placed between these well locations and the railroad tracks. In addition, two 800-foot long containment walls (e.g. slurry walls) will be needed to attempt to funnel groundwater into the PRB. The unconfined aquifer described as the Cape May Formation where elevated concentrations of lead and cadmium are present ranges in depth from 20 to 40 feet bgs

[GeoSyntec, 2000]. Therefore, the slurry/containment walls would need to be approximately 20 to 40 feet deep.

A threshold requirement to successfully implement this remedial alternative is a mobile plume of contaminants, which is not the case at the Site. A review of the Site-related data reveals that the threshold requirement is not met at the Site. Figures 4 and 5 depict the extent of lead and cadmium concentrations above NJGWQSs from 1983 to 2007. As shown, the area of impact has remained relatively stationary, but decreased in size. Because the PRB would not be effective in treating most of the bulk of the affected groundwater, the PRB alternative is only slightly more effective than the no action alternative. Thus, the PRB remedy will not be any more effective than the no action or MNA alternatives, but it would be significantly more expensive to implement.

Cost

Based upon the assumptions and construction criteria presented above, CSI estimated the cost to construct the PRB to be \$6,266,374 (Table 9). This estimate is provided in 2009 dollars, which is the estimated construction period. The cost estimate shown does not include operation and maintenance (O&M) costs or groundwater monitoring costs. The O&M costs for this remedy are estimated to be approximately \$2 million every 3-5 years to replace spent media and dispose of the waste. The groundwater monitoring costs would be similar to those presented in the MNA remedy, which is approximately \$1.1 million for thirty years of monitoring.

Modifying Criteria

State/EPA Acceptance

PRBs have been employed at numerous sites for in-situ removal of metals. The technology is recognized as effective by EPA.

Community Acceptance

The PRB alternative involves significant earth work and intrusive long-term maintenance. Notwithstanding the anticipated ineffectiveness of the PRB at the Site, the prospect of long-term intrusion into the Site to perform significant maintenance activities, the end result of which will not occur any sooner than the less intrusive no action and MNA alternatives, is likely to be viewed unfavorably by the community.

3.6 Pump and Treat – Alternative 5

3.6.1 Description of Pump and Treat

The groundwater remedial alternative that was selected in the ROD [EPA, 1994] was the “extraction and treatment of contaminated groundwater with direct discharge of the treated groundwater to the Delaware River.” This alternative, as initially described by O’Brien & Gere in the 1993 FS, involved the use of a well point system at the Site that

no longer exists. O'Brien & Gere initially specified 49 well points to contain water within the Site. Water would be pumped from these well points and manifolded into four sub-systems which would pump the water to the treatment facility. The treatment method prescribed in the FS [O'Brien & Gere, 1993] was precipitation/flocculation followed by an ion exchange polishing step. Following treatment, the water would then need to be pumped to the Delaware River. An effluent outfall would have to be constructed at the discharge location. The distance from the railroad tracks on the Site to the Delaware River is approximately 1 ½ miles.

3.6.2 Evaluation of Pump and Treat

The pump and treat remedial alternative was extensively evaluated in a pilot study performed at the Site in 1999 and described in the Phase II Technical Memorandum [GeoSyntec, 2000]. An aquifer test was performed to (i) confirm the hydraulic parameters determined by Geraghty and Miller in 1983; (ii) predict the performance of a groundwater extraction system that might be designed to remove lead and cadmium from the aquifer; and (iii) establish input parameters for capture zone modeling as requested by the EPA [GeoSyntec, 2000]. The applicable text, tables, and figures from the Phase II Technical Memorandum [GeoSyntec, 2000] regarding the aquifer test results are attached in Appendix G. The salient point obtained from the aquifer test is that although groundwater was extracted, very little lead and cadmium were removed from the subsurface in the groundwater that was extracted.

In order to calculate the length of time it would take to extract the mass of lead and cadmium calculated to be present in groundwater at the Site (see Table 9-6 in Appendix G), constant extraction concentrations of 1 µg/L and 2 µg/L for lead and cadmium, respectively, were used. These numbers are higher than the test results indicated was possible, however they provide a conservative and valid demonstration of the remedy's ability to extract these contaminants using pump and treat techniques. Based upon these assumptions, GeoSyntec calculated that it would require 61 years of constant pumping to remove the estimated 9 lbs of lead calculated to remain in groundwater at that time. The 14 lbs of cadmium calculated to be present in groundwater would require approximately 48 years [GeoSyntec, 2000] of constant pumping. The lead and cadmium concentrations are estimated to be reduced to below applicable NJGWQSs in approximately the same period, without pumping.

The Phase II Technical Memorandum [GeoSyntec, 2000] results are supported by the literature regarding inorganic contaminants in groundwater. In *Remediation of Metals-Contaminated Soils and Groundwater* [Evanko and Dzombak, 1997], the author stated that "[t]ypically metals are relatively immobile in subsurface systems as a result of precipitation or adsorption reactions." Specifically, many studies regarding lead indicate that "most lead that is released to the environment is retained in soil" [Evans, 1989]. Furthermore, the processes of adsorption, ion exchange, precipitation, and complexation with sorbed organic material limit the amount of lead that can be transported into surface water or groundwater [Evanko and Dzombak, 1997]. More recently, as described above

in Section 3.5.2, PRB studies [Wright and Conca, 2002] have demonstrated that these same reactions can be used to remove inorganic constituents from groundwater.

Cadmium is more mobile in surface water and groundwater than lead. Under acidic groundwater conditions, such as those found in the central portion of the Site, cadmium forms complexes with chloride and sulfate. Removal of cadmium from groundwater is thus performed through precipitation and sorption to mineral surfaces, particularly oxide minerals at pH levels greater than 6 [Evanko and Dzombak, 1997].

The studies of the mobility of lead and cadmium in groundwater, and the geochemistry of these metals in groundwater, suggest that pumping and treating groundwater to remove these inorganic constituents is not the preferred methodology. When pumping is conducted in an area where the groundwater pH is low, the pumping process may initially allow removal of a minor amount of constituents at that location. However, as pumping continues, water is drawn into that well from more distant areas which affects the geochemical characteristics of the area pumped. This can be counterproductive as the changes in geochemical parameters cause the mobility of the COCs to decrease temporarily, thus reducing the ability to extract them. The ineffectiveness of the pump and treat technique was demonstrated by the aquifer test performed for the Phase II Technical Memorandum [GeoSyntec, 2000], the results of which are provided in Appendix G. The results indicated that lower concentrations of the metals were removed as pumping progressed.

Threshold Criteria

Overall Protection of Human Health and the Environment

Based upon the results of the aquifer test reported in the Phase II Technical Memorandum (Appendix G), this alternative is unlikely to appreciably reduce concentrations of lead and cadmium in groundwater in a reasonable time period. Therefore, the protection of human health and the environment through pumping and treating groundwater is not anticipated to be better than the MNA or the no action alternatives. Since the lead and cadmium concentrations in groundwater will only be minimized in a localized area, the protection of human health and the environment through this alternative is thus poor.

Compliance with ARARs

The following ARARs have been determined to be potentially applicable to this alternative:

Potential Chemical Specific ARARs:

Federal

- Clean Water Act, Water Quality Criteria

- RCRA Ground Water Protection Standards (40 CFR Part 264.94)
- Federal Water Quality Criteria (51 *Federal Register* 436665)

New Jersey

- New Jersey Ground Water Quality Standards (NJGWQS) (NJAC 7:9-6)

Potential Action Specific ARARs

Federal

- RCRA Groundwater Monitoring and Protection Standards (40 CFR 264, Subpart F)
- Clean Water Act – NPDES Permitting Requirements for Discharge of Treatment System Effluent (40 CFR 122-125)
- EPA Action Level for Lead in Drinking Water

New Jersey

- New Jersey Pollutant Discharge Elimination System Regulations (NJPDES) and Effluent Limitations (NJAC 7:14A et seq)

Potential Location Specific ARARs

Federal

- Fish and Wildlife Coordination Act (16 USC 661 et seq.)
- National Environmental Policy Act (42 USC 4341 et seq.)
- Endangered Species Act
- Coastal Zone Management Act
- Farmland Protection Policy Act

New Jersey

- New Jersey Rules on Coastal Resources and Development (7:7E-1.1 et seq.)
- New Jersey Freshwater Wetlands Regulation

Concentrations of lead and cadmium in groundwater will only be reduced minimally in a localized area by pumping and treating groundwater. Attainment of ARARs will depend primarily upon the continued decline in lead and cadmium concentrations in groundwater without active remediation, as described for the no action and MNA alternatives. Additional action-specific ARARs would need to be considered for this remedy such as the Clean Water Act NPDES permitting requirements and NJPDES effluent limitations for the discharge of extracted groundwater. These ARARs

would require additional monitoring and permitting activities not associated with other remedial alternatives, except for the PRB alternative.

Primary Balancing Criteria

Long-Term Effectiveness and Permanence

The long-term effectiveness of the pump and treat alternative would be similar to the monitored natural attenuation and no action alternatives. The reduction in concentrations of lead and cadmium in groundwater would be somewhat affected by active pumping and treating of impacted groundwater, but the anticipated length of time to achieve RAOs using this alternative would remain in the 30-50 year timeframe. The permanence of the pump and treat alternative would also be similar to the MNA and no action alternatives. The majority of the lead and cadmium would be bound to native soils or precipitated into low-solubility complexes. Thus, once concentrations have been reduced to levels below the RAOs, it is anticipated that this would be a permanent condition.

Reduction of Toxicity, Mobility, or Volume

As discussed above under long-term effectiveness and permanence, it is anticipated that RAOs would be achieved within 30 to 50 years. Toxicity, mobility, and the volume of lead and cadmium-impacted groundwater would steadily decline to insignificant levels in the same period.

The limited mobility of these contaminants in groundwater has been documented through historical groundwater monitoring data provided in Table 2 and shown in Figures 4 and 5. These data demonstrate that the area of impacted groundwater containing elevated concentrations of lead and cadmium has remained in the same location, but has decreased in volume since 1983.

As discussed above under the no action alternative, the volume of impacted groundwater has declined considerably since the 1980s. The current mass of lead remaining in groundwater at the Site was calculated to be 0.5% of the mass in 1983. The current mass of cadmium in groundwater at the Site was calculated to be 9% of the 1988 value. Therefore, the amount of contaminants in groundwater at the Site has reduced dramatically in the more than 20 years since monitoring began without active remediation efforts. The reduction in mass achieved through the pump and treat alternative will not significantly improve compared to the no action alternative and the timeframe for reduction in volume of impacted groundwater would remain relatively unchanged.

Short-Term Effectiveness

The pump and treat alternative may promote a slight reduction in concentrations of lead and cadmium in groundwater in the short-term. However, the Phase II [GeoSyntec, 2000] aquifer test results (Appendix G) indicate that after the initial lead and

cadmium is removed in the vicinity of the well point by pumping, the rate of lead and cadmium removal quickly approaches zero. Thus, a short-term benefit may be realized from the pump and treat alternative, but it will have only a minor effect on overall groundwater quality.

Feasibility to Implement

The construction of a groundwater extraction system requires reasonably routine construction techniques. The discharge of treated water, which as specified in the ROD will require discharge to the Delaware River, will necessitate effective wastewater treatment techniques that operate continually. Discharge to the Delaware River will require the construction of approximately 1.5 miles of discharge piping and appurtenances. The piping will require protection for heavy equipment and the elements and will have to include access for repair and maintenance. Access to properties owned by others will need to be negotiated and secured for an extended period. Should this alternative be selected, then additional discharge options should be considered.

Cost

A cost estimate for the pump and treat alternative of \$10.1 million was calculated in 1993 [O'Brien & Gere, 1993]. The actual cost of the alternative, including long term operation and maintenance, may be somewhat lower due to a smaller area of impact at the Site today than was present in 1993.

Modifying Criteria

State/EPA Acceptance

Pump and treat is a widely accepted remedial alternative by both state and federal regulators for some contaminants. Its acceptance as a remedy for lead and cadmium may be suspect due to its limited effectiveness. However, based on its prominent use in the past at other sites, it is anticipated that, should this remedy be selected, it would be accepted by the regulatory community.

Community Acceptance

The implementation of this remedy would involve the construction of a groundwater extraction, treatment and discharge piping that would need to be in place for an extended period. The footprint of the groundwater pump and treat operation would preclude the use of a portion of the Site from further development for approximately 30 to 50 years. Additionally, long-term access to the Site and other properties will be required to maintain and repair equipment and piping. It is expected that the local community would prefer to promote a beneficial reuse of the Site in the near future. Thus, the community acceptance of this remedy is expected to be poor compared to other available remedies.

4. COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

4.1 Overview

The evaluation of alternatives has been summarized in the comparison matrix presented as Table 10.

4.2 Remedial Alternative Matrix Discussion

Upon review of the alternative comparison matrix presented in Table 10, two alternatives appear to be reasonably well suited for groundwater remediation at the Site. Those alternatives include MNA and reagent injection. Of the two, reagent injection is likely to achieve RAOs in a more expeditious manner, which would more rapidly provide higher protection of human health and the environment and more rapidly promote a more productive use of the Site.

The implementation of the MNA alternative is estimated to achieve the RAOs in a period of approximately 30 to 50 years. However, MNA would require institutional controls restricting the use and access to groundwater at the Site throughout the remediation process, which is a potential concern regarding future productive reuse of the Site.

Reagent injection has the potential to achieve RAOs within a shorter time period, perhaps less than ten years. Institutional controls restricting access to and use of groundwater will still be required. However, the period through which restrictions are in place will be shorter than for the no action or MNA alternatives. The reagent injection alternative will likely be satisfactory to the local community, providing the possibility of less restrictive Site reuse sooner.

The PRB and pump and treat alternatives are expensive and considerably less effective in achieving RAOs than reagent injection based on the technical limitations described in this Focused Feasibility Study. Therefore, further discussion of alternatives should reasonably focus on testing the efficacy of reagent injection and/or MNA at the Site, and ultimately the remedy selection should be based on a full consideration of all of the above alternatives including the results of bench and pilot scale testing of reagent injection, as described in Section 5.2, and any results of testing designed to evaluate MNA.

5. REMEDIAL ALTERNATIVES SELECTION AND IMPLEMENTATION

5.1 Remedial Alternative Selection

As discussed above, reagent injection appears to be the preferred alternative for the Site based on the more efficient achievement of RAOs. However, MNA can also be effective although it requires significantly more time to achieve RAOs. By achieving RAOs sooner, human health and the environment will be better protected, the cost of the remedy may be minimized, and a less restrictive reuse of the Site may ensue in the reasonably near future.

5.2 Additional Pilot/Bench Scale Studies

A pilot study is needed to optimize the reagent injection remedy. A reasonable pilot study may consist of the installation of 2 to 3 well points installed near well SS, where groundwater pH is low. The well points would be used to adjust the pH in that vicinity and to inject the sodium tripolyphosphate. Groundwater monitoring should be included to evaluate the impact on lead and cadmium concentrations in groundwater. CSI believes that the groundwater monitoring could be achieved using the existing monitoring well network at the Site. The cost for the pilot study is estimated to be approximately \$40,000. The pilot study will require approximately two months to complete. Should the reagent injection alternative be chosen, a work plan outlining the specifics of the pilot study will be presented to the EPA for review and concurrence regarding the scope of the pilot study and methodology to be used.

5.3 Preliminary Schedule

A schedule for the implementation of a groundwater remedy for this Site is dependent on the remedy selected and the length of time required to achieve regulatory and public acceptance of the chosen remedy. After the remedial alternative is selected, a preliminary schedule for implementation of the remedy will be incorporated into the associated remedial action plans.

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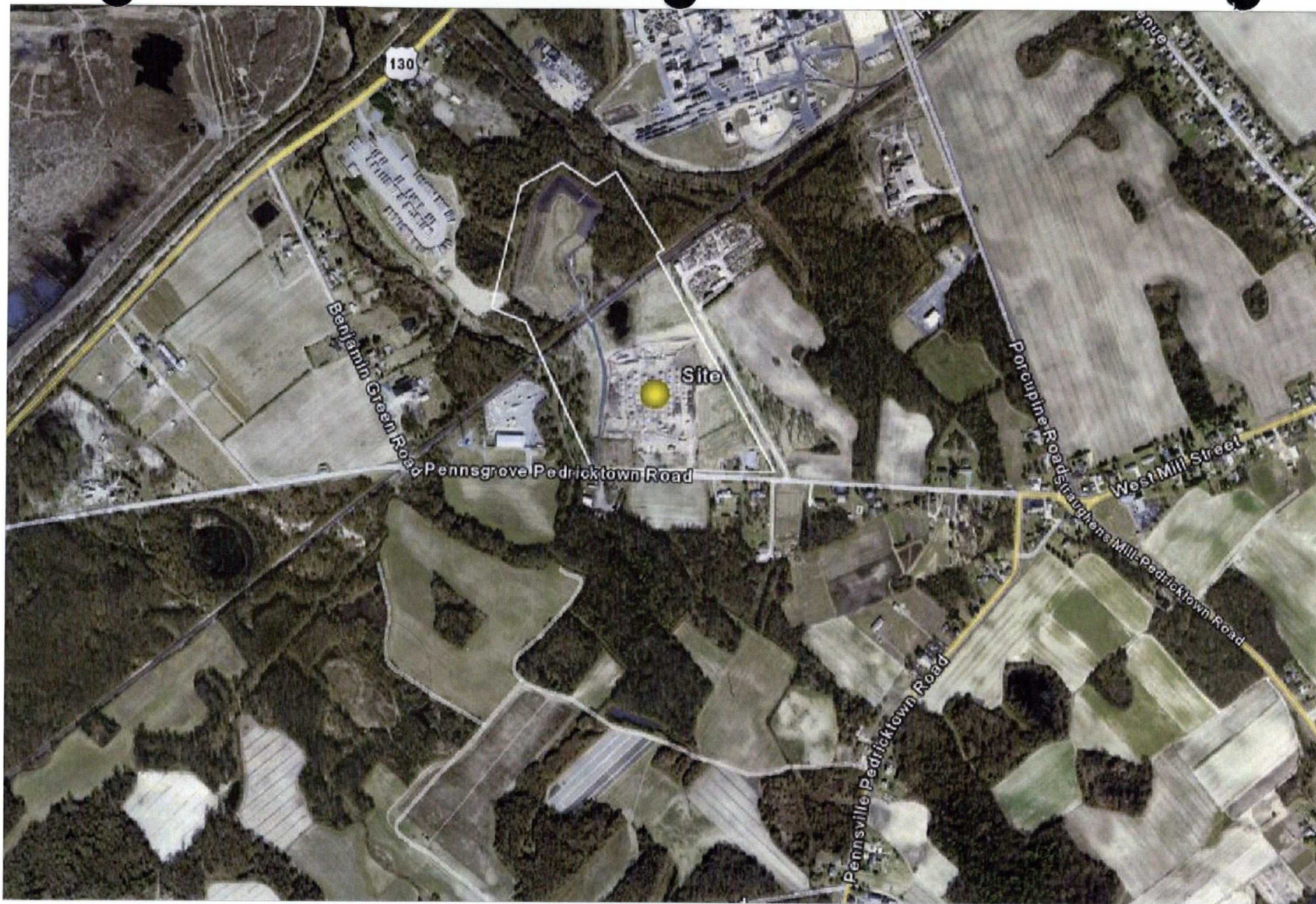
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FIGURES



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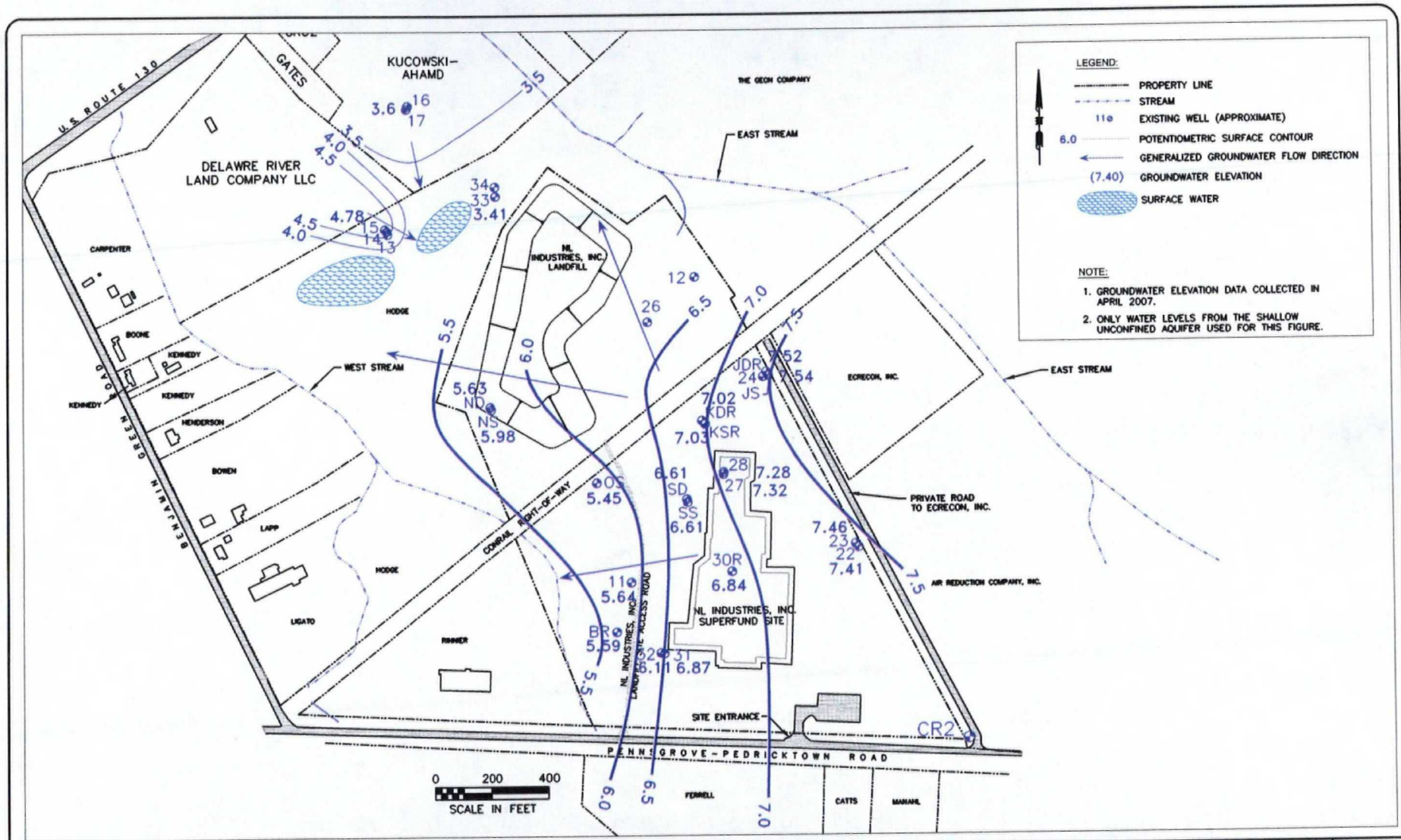
918 Chesapeake Ave.
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Site Location

NL Industries Superfund Site
Pedricktown, NJ

FIGURE

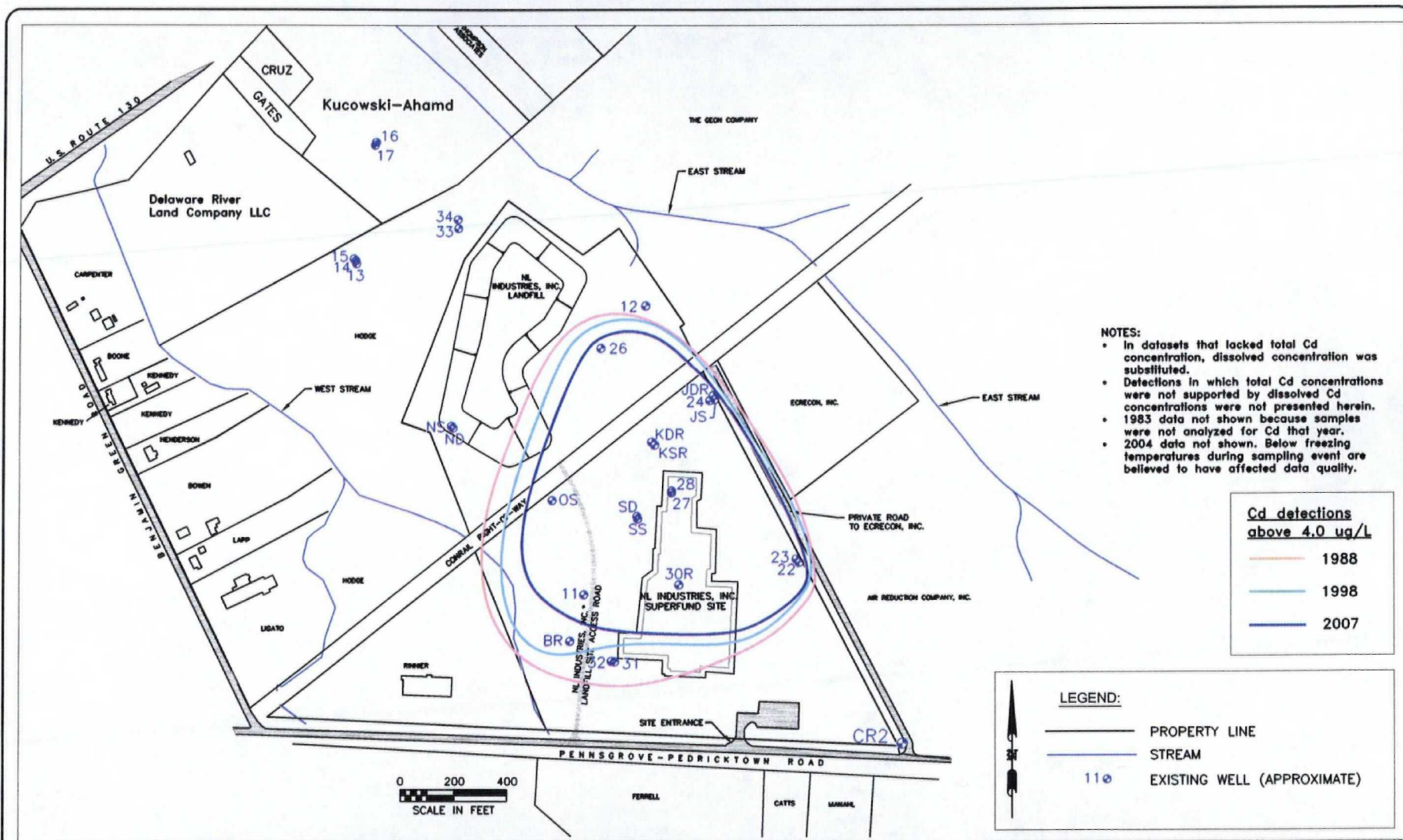
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Groundwater Elevations and Inferred
Flow Direction, April 2007
NL Industries Superfund Site
Pedricktown, NJ

FIGURE
3



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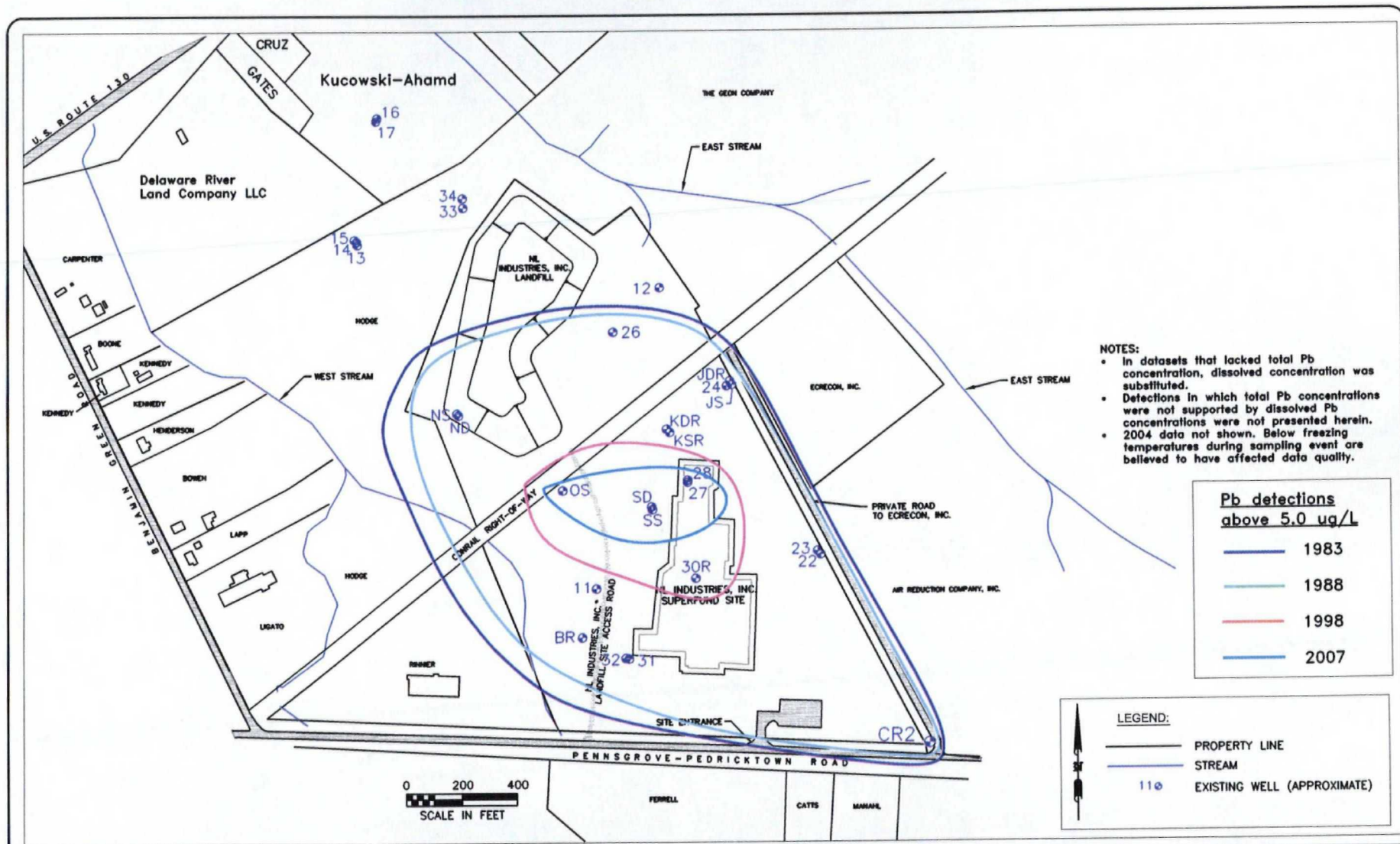
Data Source:

- CSI Environmental - Groundwater Monitoring Report
- GeoSynfec Phase II Technical Memorandum (2000)
- O'Brian & Gere Remedial Investigation (1990)

Historical Extent of Cd Concentrations in Groundwater
Greater Than New Jersey Groundwater Quality Standard

NL Industries Superfund Site
Pedricktown, NJ

FIGURE
4



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Data Source:

- CSI Environmental - Groundwater Monitoring Report
- GeoSyntec Phase II Technical Memorandum (2000)
- O'Brian & Gere Remedial Investigation (1990)

**Historical Extent of Pb Concentrations in Groundwater
Greater Than New Jersey Groundwater Quality Standard**

NL Industries Superfund Site
Pedricktown, NJ

FIGURE
5

34	33
Cd - ND	Cd - 3.0 J
Cd(dis) - ND	Cd(dis) - ND
Pb - 16.3 J	Pb - ND
Pb(dis) - ND	Pb(dis) - ND

13, 14, & 15
Cd - ND
Cd(dis) - ND
Pb - ND
Pb(dis) - ND

ND	NS
Cd - ND	Cd - 1.5 U
Cd(dis) - ND	Cd(dis) - 1.4U
Pb - 22.2 J	Pb - 41.6 J
Pb(dis) - ND	Pb(dis) - ND

OS
Cd - 3.9J
Cd(dis) - 4.2J
Pb - 388
Pb(dis) - 320

SD	SS
Cd - 149J	Cd - 10.6J
Cd(dis) - 156J	Cd(dis) - 11.8J
Pb - 31	Pb - 82.9
Pb(dis) - 90.4	Pb(dis) - 13

30R
Cd - 163J
Cd(dis) - 169J
Pb - ND
Pb(dis) - 1.6J

11
Cd - 110J
Cd(dis) - 113J
Pb - ND
Pb(dis) - ND

BR
Cd - ND
Cd(dis) - 1.1U
Pb - ND
Pb(dis) - ND

31	32
Cd - 1.5J	Cd - ND
Cd(dis) - 1J	Cd(dis) - ND
Pb - 20.6J	Pb - ND
Pb(dis) - ND	Pb(dis) - ND

16	17
Cd - ND	Cd - ND
Cd(dis) - ND	Cd(dis) - ND
Pb - ND	Pb - ND
Pb(dis) - ND	Pb(dis) - ND

12
Cd - ND
Cd(dis) - ND
Pb - ND
Pb(dis) - ND

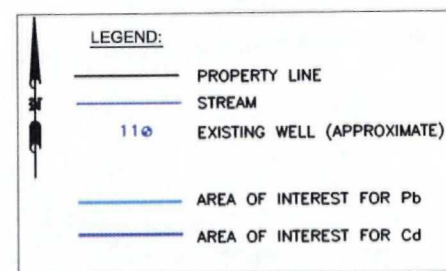
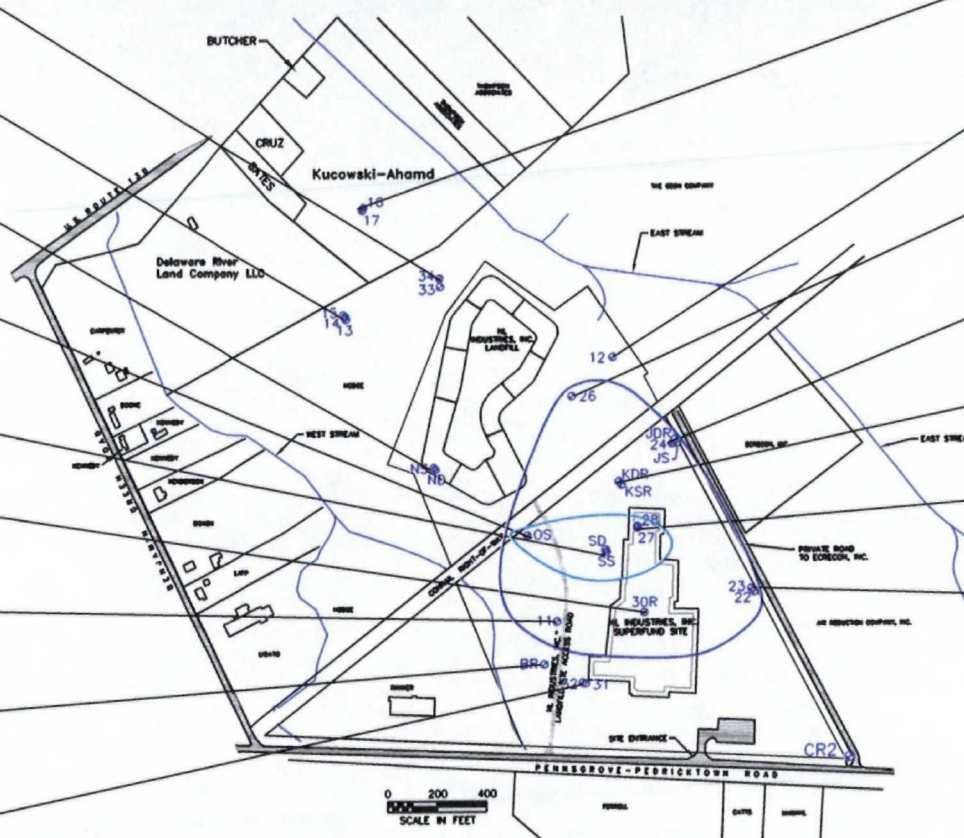
26
Cd - 12.6J
Cd(dis) - 13J
Pb - 1.4J
Pb(dis) - ND

JDR	24	JS
Cd - 54.5J	Cd - ND	Cd - 3.9 J
Cd(dis) - 60.8J	Cd(dis) - ND	Cd(dis) - 3 J
Pb - ND	Pb - ND	Pb - 1.0 J
Pb(dis) - ND	Pb(dis) - ND	Pb(dis) - ND

KSR	KDR
Cd - 7.6 J	Cd - 141 J
Cd(dis) - 3.8U	Cd(dis) - 166J
Pb - ND	Pb - ND
Pb(dis) - ND	Pb(dis) - ND

27	28
Cd - 8.5	Cd - 151
Cd(dis) - 7.1	Cd(dis) - 163
Pb - 6.2	Pb - ND
Pb(dis) - 3.6	Pb(dis) - ND

22	23
Cd - 7.3 J	Cd - 25.8 J
Cd(dis) - 7.2J	Cd(dis) - 26.7
Pb - ND	Pb - ND
Pb(dis) - ND	Pb(dis) - ND



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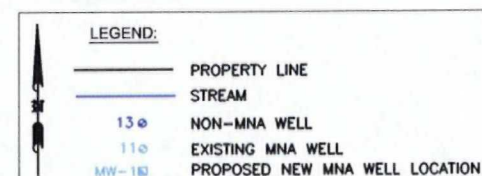
Data Source:
CSI Environmental - NL Groundwater Report 2007

Cd & Pb Concentrations in Groundwater
April, 2007
NL Industries Superfund Site
Pedricktown, NJ

FIGURE
6

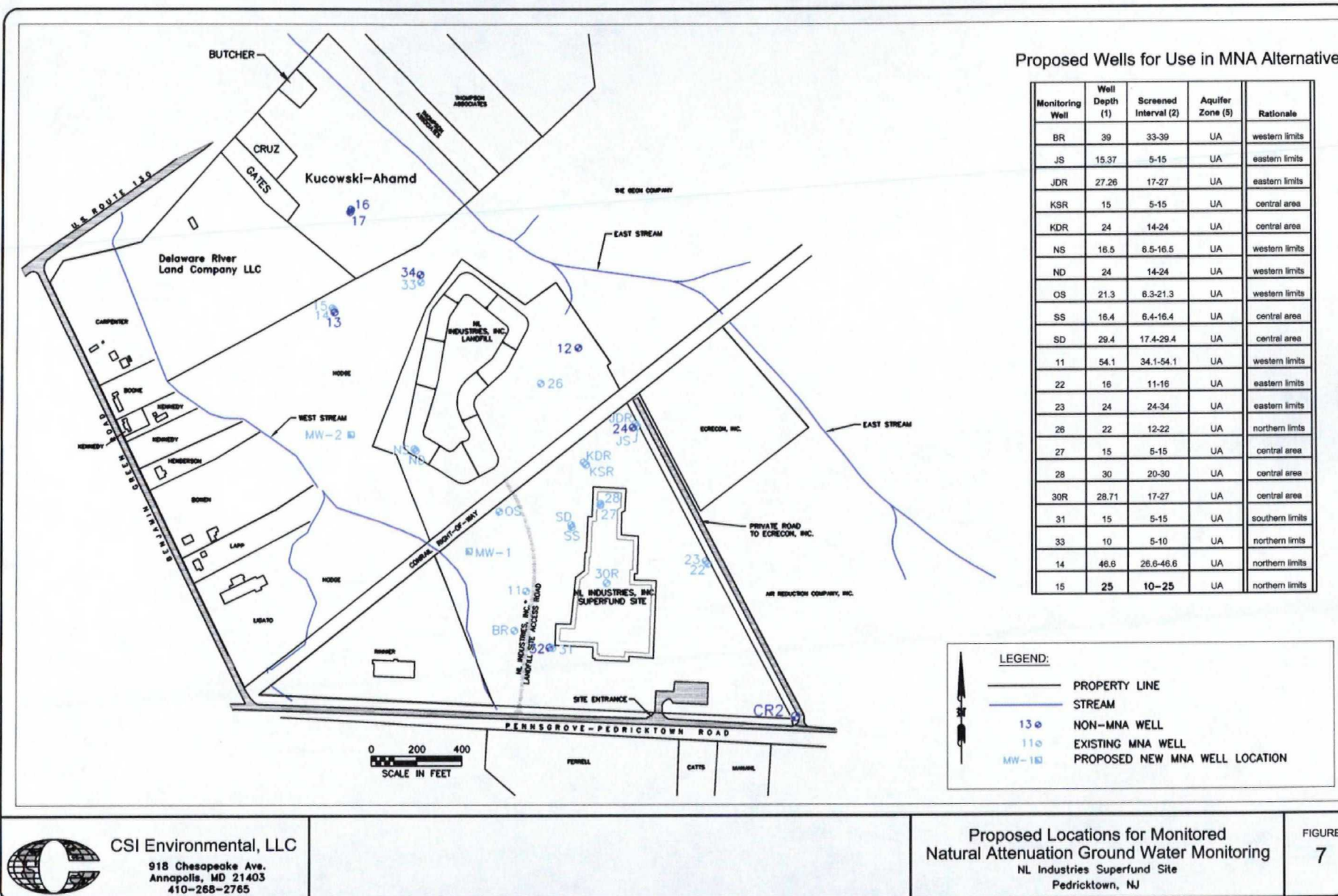
Proposed Wells for Use in MNA Alternative

Monitoring Well	Well Depth (1)	Screened Interval (2)	Aquifer Zone (5)	Rationale
BR	39	33-39	UA	western limits
JS	15.37	5-15	UA	eastern limits
JDR	27.26	17-27	UA	eastern limits
KSR	15	5-15	UA	central area
KDR	24	14-24	UA	central area
NS	16.5	6.5-16.5	UA	western limits
ND	24	14-24	UA	western limits
OS	21.3	6.3-21.3	UA	western limits
SS	16.4	6.4-16.4	UA	central area
SD	29.4	17.4-29.4	UA	central area
11	54.1	34.1-54.1	UA	western limits
22	16	11-16	UA	eastern limits
23	24	24-34	UA	eastern limits
26	22	12-22	UA	northern limits
27	15	5-15	UA	central area
28	30	20-30	UA	central area
30R	28.71	17-27	UA	central area
31	15	5-15	UA	southern limits
33	10	5-10	UA	northern limits
14	46.6	26.6-46.6	UA	northern limits
15	25	10-25	UA	northern limits



Proposed Locations for Monitored
Natural Attenuation Ground Water Monitoring
NL Industries Superfund Site
Pedricktown, NJ

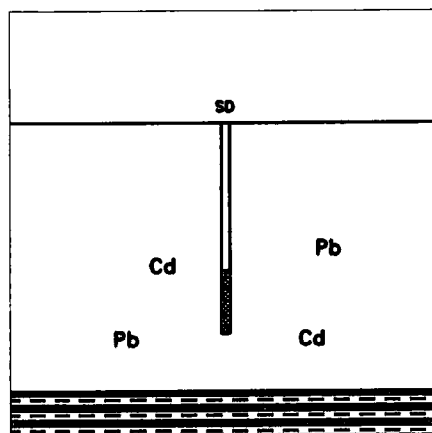
FIGURE
7



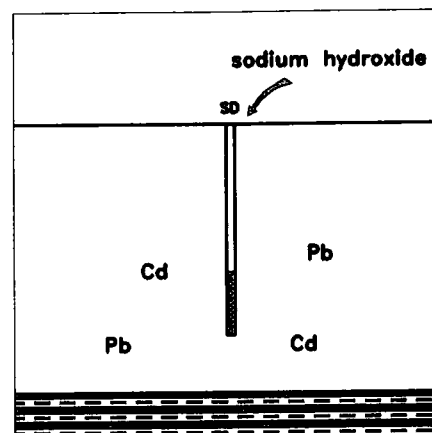
CSI Environmental, LLC
918 Chesapeake Ave.
Annapolis, MD 21403
410-268-2765

Before reagent injection

- Cd concentration = 149 ppb
- Pb concentration = 31 ppb
- PH = 3.08



Before reagent injection



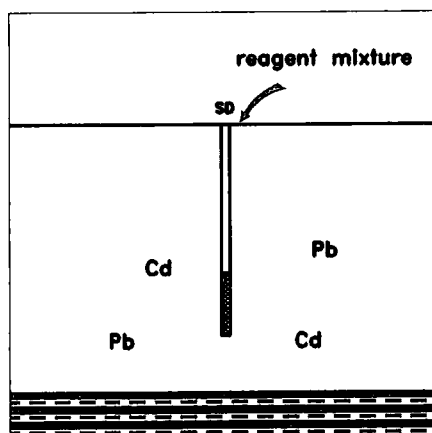
Stage 1 - PH Adjustment

Stage 1 - Adjust PH

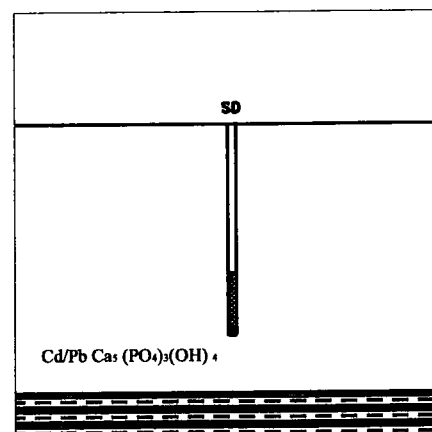
- An alkaline PH is necessary to stimulate metal phosphate formation. A 5% sodium hydroxide solution is introduced to adjust the well's PH to approximately 8.5.

Stage 2 - Reagent Injection

- Mixture of sodium tri-polyphosphate and calcium chloride added to well.



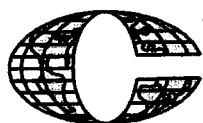
Stage 2 - Reagent Injection



After reagent injection

After Reagent Injection

- Cd & Pb ground water concentrations not detected after reagent injection.
- Cd & Pb form metal phosphates ($\text{Cd/Pb Ca}_3(\text{PO}_4)_2(\text{OH})_2$) becoming insoluble & inert.



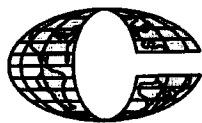
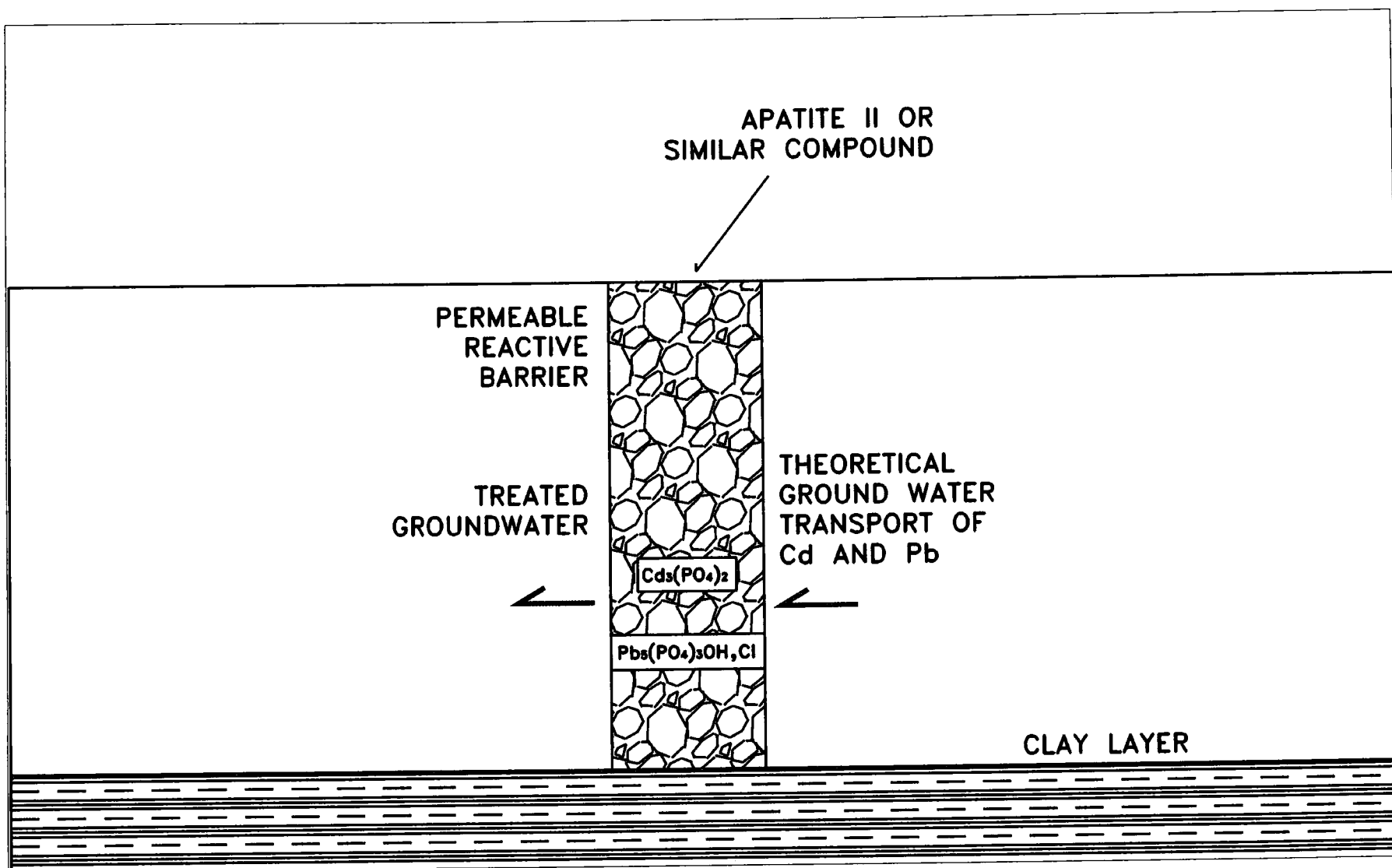
CSI Environmental, LLC

918 Chesapeake Ave.
Annapolis, MD 21403
410-268-2765

Data based on bench scale treatability study by Water Remediation Services, Inc (2007).

Conceptual Application of
Reagent Injection Alternative

FIGURE
8



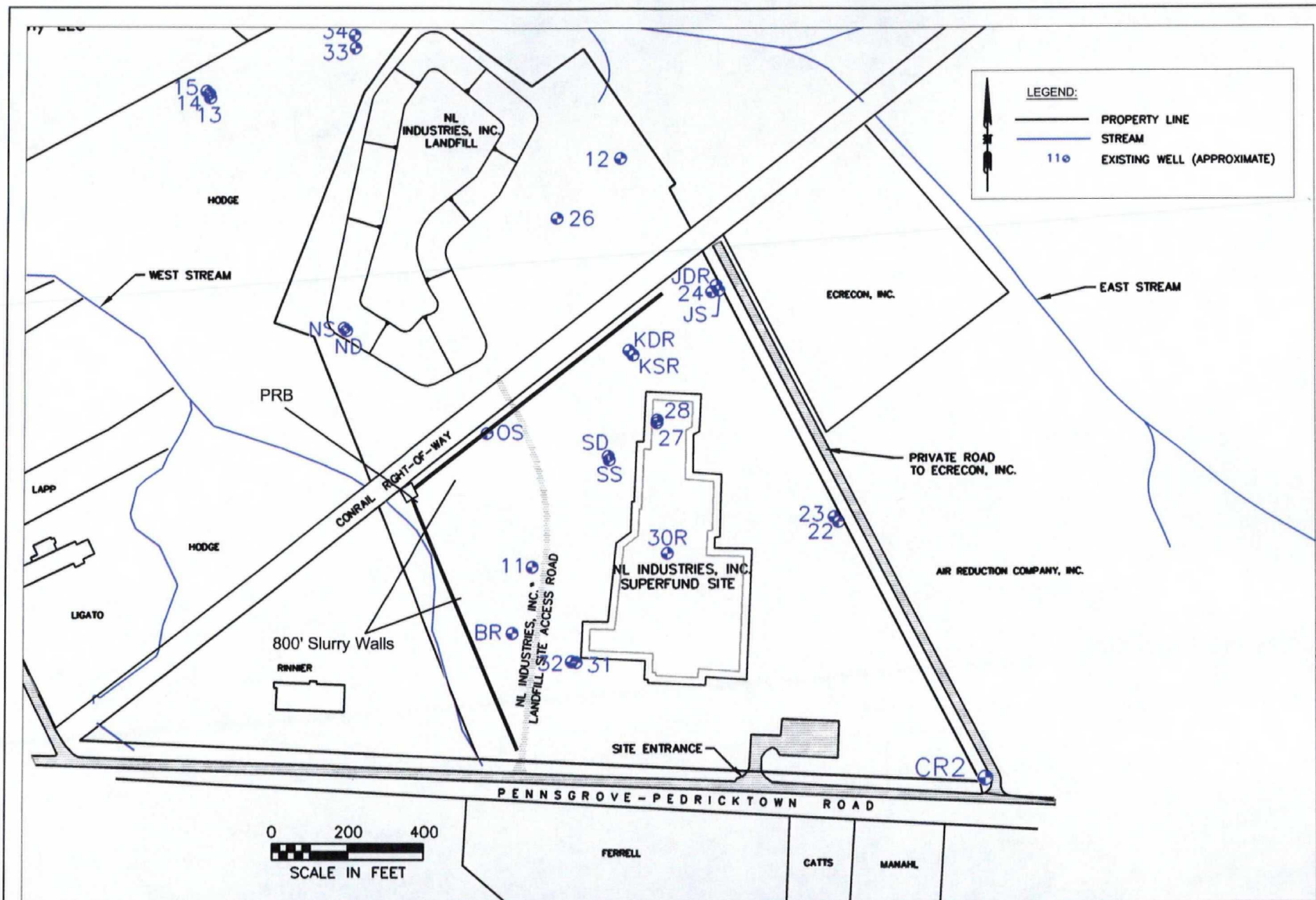
CSI Environmental, LLC

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Annapolis, MD 21403
410-268-2765

Cross Section View Of
Permeable Reactive Barrier

FIGURE

9



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918 Chesapeake Ave.
Annapolis, MD 21403
410-268-2765

Conceptual PRB & Containment Wall Location

NL Industries Superfund Site
Pedricktown, NJ

FIGURE
10

TABLES

Table 1
Data Summary for the April 2007 Groundwater Sampling
NL Industries Superfund Site
Pedricktown, New Jersey

	Well Number												
Parameter (ug/L)	11	12	13	14	15	16	17	22	23	24	26	27	RAO
Inorganics													
Total Cadmium		ND	ND	ND	ND	ND	ND			ND			4
Dissolved Cadmium		ND	ND	ND	ND	ND	ND			ND			4
Total Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.4 J		5
Dissolved Lead	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.6	5
Organics													
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	700
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.66 J	ND	ND	-
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6
Isobutane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
1,1-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
1,1-Dichloroethane	0.99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	70
cis-1,2-Dichloroethene	0.68	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
Methylene Chloride	0.39 U	ND	0.64 U	0.42 U	0.38 U	0.28 U	0.31 U	ND	ND	ND	ND	0.4 U	-
Methyl tert-butyl Ether	ND	ND	ND	ND	ND	0.69	ND	ND	ND	ND	ND	ND	-
Tetrachloroethene		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,000
1,1,1-Trichloroethane	2.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	26
Trichloroethene	0.29 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
Vinyl Chloride	ND		ND	ND	ND	ND	ND	ND	ND		ND	ND	0.08

U = Parameter was flagged in data validation and are considered non-detects.

⁽¹⁾ 100 is a duplicate sample obtained from monitoring well 28.

⁽²⁾ 101 is a duplicate sample obtained from monitoring well KDR.

⁽³⁾ 102 is a duplicate sample obtained from monitoring well 31.

⁽⁴⁾ Two rinseate blanks were collected (RB-1 and RB-2). RB-1 was collected from the pump used at well 17, RB-2 was collected from the pump used at well 26, both samples were collected using field blank water supplied by Chemtech.

⁽⁵⁾ FB-1 is a field blank collected with water supplied by Chemtech, water used for final rinse during decontamination events.

⁽⁶⁾ Four trip blanks were included with the samples. TB-1, TB-2, TB-3, and TB-4.

N/A = Not Applicable

ND = Non Detect

RDL = Required Detection Limit (Contract)

MDL = Method Detection Limit (Instrument)

RAO = Remedial Action Objective. RAO is the lowest value out of NJGWQS, NJMCL, or MCL as defined in the ROD. If not specified in ROD, RAO left blank.

Note:

Shaded cells and bold numbers indicate an exceedance of the RAO.

Table 1
Data Summary for the April 2007 Groundwater Sampling
NL Industries Superfund Site
Pedricktown, New Jersey

	Well Number													
Parameter (ug/L)	28	MW-100*	30R	31	102 ⁽²⁾	32	33	34	J8	JDR	K8R	KDR	101 ⁽²⁾	RAO
Inorganics														
Total Cadmium				1.5 J	1.2 J	ND	3.0 J	ND	3.9 J					4
Dissolved Cadmium				1 J	ND	ND	ND	ND	3 J		3.8 U			4
Total Lead	ND	ND	ND			ND	ND		1.0 J	ND	ND	ND	ND	5
Dissolved Lead	ND	ND	1.8 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Organics														
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	700
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6
Isobutane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—
1,1-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
1,1-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	70
cis-1,2-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—
Methylene Chloride	0.35 U	0.29 U	ND	3.0 U	ND	ND	0.45 U	0.38 U	ND	0.5 U	0.33 U	0.28 U	ND	—
Methyl tert-butyl Ether	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1,000
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	28
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—
Vinyl Chloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08

J = Data indicates the presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The concentration given is an approximate value.
 U = Parameter was flagged in data validation and are considered non-detects.

⁽¹⁾ 100 is a duplicate sample obtained from monitoring well 28.

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⁽³⁾ 102 is a duplicate sample obtained from monitoring well 31.

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⁽⁵⁾ FB-1 is a field blank collected with water supplied by Chemtech, water used for final rinse during decontamination events.

⁽⁶⁾ Four trip blanks were included with the samples. TB-1, TB-2, TB-3, and TB-4.

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Table 1
Data Summary for the April 2007 Groundwater Sampling
NL Industries Superfund Site
Pedricktown, New Jersey

	Well Number						QA/QC Samples								
Parameter (ug/L)	SS	SD	NS	ND	OS	BR	RB-1 ⁽⁴⁾	RB-2 ⁽⁴⁾	FB-1 ⁽⁵⁾	TB-1 ⁽⁶⁾	TB-2 ⁽⁶⁾	TB-3 ⁽⁶⁾	TB-4 ⁽⁶⁾	RAO	
Inorganics															
Total Cadmium			1.5 U	ND	3.8 J	ND	ND	ND	ND	NA	NA	NA	NA	4	
Dissolved Cadmium			1.4 U	ND		1.1 U	ND	1.1 U	ND	NA	NA	NA	NA	4	
Total Lead						ND	ND	ND	ND	NA	NA	NA	NA	5	
Dissolved Lead			ND	ND		ND	ND	ND	ND	NA	NA	NA	NA	5	
Organics															
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	9.4	ND	ND	ND	ND	700	
Benzene	ND	0.68	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	
Chloroform	ND	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6	
Isobutane	ND	ND	ND	ND	ND	ND	ND	ND	2.7 J	ND	ND	ND	ND	—	
1,1-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1	
1,1-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	70	
cis-1,2-Dichloroethene	ND	0.35 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	
Methylene Chloride	ND	0.5 U	ND	ND	ND	ND	2.2 U	2 U	3 U	0.55 U	0.84 U	0.45 U	2.5 U	—	
Methyl tert-butyl Ether	ND	ND	ND	0.41 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	
Toluene	ND	0.5 J	ND	ND	ND	ND	0.25 J	0.33 J	0.37 J	ND	ND	ND	ND	1,000	
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	26	
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	—	
Vinyl Chloride	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08	

J = Data indicates the presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The concentration given is an approximate value.

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Note:

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TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	11								12						RAO
	1983	1988	1989	1990	1997	1998	2004	2007	1989	1990	1997	1998	2004	2007	
Inorganic Compounds (ug/L)															
Total Cadmium	NM	NM	NM	NM	E	2.4	2.1	1.0	NM	NM	ND	ND	ND	ND	4
Dissolved Cadmium	NM			NM	E	2.3	2.1	1.1	ND	NM	NM	0.9 B	ND	ND	4
Total Lead		NM	NM	NM		1.4 JB	4	ND	NM	NM	ND	ND	4.9	ND	5
Dissolved Lead	NM		NM	NM	ND	ND		ND	NM	2.3	NM	ND	ND	ND	5
Volatile Organic Compounds (ug/L)															
Total Organics	NM	NM	5124	2974	1.52	NM	15	5.86	NM	NM	11.3	NM	3.7	9.3	NA

Notes:

NJGWQS = New Jersey Groundwater Quality Standards

NJMCL = New Jersey Maximum Contaminant Level

PQL = Practical Quantitation Limit

* = Original well damaged during the remedial action, replaced in 2004

RAO = Remedial Action Objective. RAO is the lowest value out of NJGWQS, NJMCL, or MCL as defined in the ROD.

ND = Not detected above the laboratories limit of detection (LOD)

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NA = Not Applicable

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B = Value was lesser than the Contract-required LOD, but greater than the instrument LOD

E = Estimated value based on the presence of an interference

Shaded and bold values indicate an exceedence of the NJGWQS

The 2004 data quality is suspected to have been affected by freezing temperatures during sample collection.

TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	13	14	15					16	17				22			RAO
	2007	2007	1989	1990	1997	2004	2007	2007	1989	1990	1997	2007	1998	2004	2007	
Inorganic Compounds (ug/L)																
Total Cadmium	ND	ND	NM	NM	ND	NM	ND	ND	NM	NM	2.3 JE	ND				4
Dissolved Cadmium	ND	ND	ND	ND		NM	ND	ND	ND	ND	NM	ND		ND		4
Total Lead	ND	ND	NM	NM	4.5	NM	ND	ND	NM	NM		ND	1.9 B		ND	5
Dissolved Lead	ND	ND	NM	2.1	ND	NM	ND	ND	NM	1.6	NM	ND	4.9	ND	ND	5
Volatile Organic Compounds (ug/L)																
Total Organics	ND	ND	NM	NM	ND	NM	ND	0.69	NM	NM	1.9	ND	NM	ND	ND	NA

Notes:

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TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	23			24		26			27			28			RAO
	1998	2004	2007	2004	2007	1998	2004	2007	1998	2004	2007	1998	2004	2007	
Inorganic Compounds (ug/L)															
Total Cadmium				ND	ND	ND				2.2 J					4
Dissolved Cadmium		ND		ND	ND		ND			ND			ND		4
Total Lead	1.6 B	3.6	ND	4.9	ND	ND		1.4 J		4.2			4.2	ND	5
Dissolved Lead	1.5 B	ND	ND	4.3	ND		ND	ND		ND	3.3		ND	ND	5
Volatile Organic Compounds (ug/L)															
Total Organics	NM	ND	ND	5.26	5.56	NM	ND	ND	NM	ND	ND	NM	ND	ND	NA

Notes:

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TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	30R*			31			32			33			34			RAO
	1998	2004	2007	1998	2004	2007	1998	2004	2007	1998	2004	2007	1998	2004	2007	
Inorganic Compounds (ug/L)																
Total Cadmium				ND	ND	1.5 J	ND	ND	ND	ND	0.5 J	3.0 J	ND	ND	ND	4
Dissolved Cadmium		ND		ND	ND	1.0 J	ND	ND	ND	ND	0.4 J	ND	ND	ND	ND	4
Total Lead		3.2	ND	ND			ND	2.3 J	ND	1.6 B	ND	ND		ND		5
Dissolved Lead		ND	1.6 J	ND	2.8 J	ND	ND	ND	ND	ND	ND	ND	ND	2.4 J	ND	5
Volatile Organic Compounds (ug/L)																
Total Organics	NM	ND	ND	NM	ND	ND	NM	ND	ND	NM	ND	ND	NM	ND	ND	NA

Notes:

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TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	JS			JDR*						KSR*					RAO
	1998	2004	2007	1983	1988	1997	1998	2004	2007	1983	1988	1997	2004	2007	
Inorganic Compounds (ug/L)															
Total Cadmium	1.4 B	3.9 J	3.9 J	NM	NM	1.5	2.0	1.5	2.0	NM	NM	1.5	2.0	2.0	4
Dissolved Cadmium	1.5 B	1.5 J	3.0 J	NM	1.5	7.0	2.0	1.5	2.0	NM	1.5	2.0	2.0	ND	4
Total Lead	ND	4	1.0 J	1.5	NM	4.1 B	ND	1.5	ND	1.5	NM	1.5	2.0	ND	5
Dissolved Lead	ND	3	ND	NM	1.5	ND	ND	1.5	ND	NM	1.5	ND	4.1	ND	5
Volatile Organic Compounds (ug/L)															
Total Organics	NM	ND	ND	NM	NM	0.27	NM	ND	ND	NM	NM	ND	ND	ND	NA

Notes:

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NJMCL = New Jersey Maximum Contaminant Level

PQL = Practical Quantitation Limit

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RAO = Remedial Action Objective. RAO is the lowest value out of NJGWQS, NJMCL, or MCL as defined in the ROD.

ND = Not detected above the laboratory limit of detection (LOD)

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The 2004 data quality is suspected to have been affected by freezing temperatures during sample collection.

TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	KDR*							SS			RAO
	1983	1988	1989	1990	1997	2004	2007	1998	2004	2007	
Inorganic Compounds (ug/L)											
Total Cadmium	NM	NM	NM	183	16.5	87	17.0	22.7	16.5	11.0	4
Dissolved Cadmium	NM	2.1	1.2	NM	18.0	22.1	16.5	11.0	ND	11.0	4
Total Lead		NM	NM	23	3.2	1.1	ND	ND	3.2	3.2	5
Dissolved Lead	NM		19.4	NM	ND	1.2	ND	ND	ND	4.8	5
Volatile Organic Compounds (ug/L)											
Total Organics	NM	NM	NM	NM	ND	0.96	ND	NM	1.9	ND	NA

Notes:

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The 2004 data quality is suspected to have been affected by freezing temperatures during sample collection.

TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	SD								NS							RAO
	1983	1988	1989	1990	1997	1998	2004	2007	1983	1988	1989	1997	1998	2004	2007	
Inorganic Compounds (ug/L)																
Total Cadmium	NM	NM	NM	NM	17.1E	15.5	15.4	14.9	NM	NM	NM	ND	0.8 B	0.6 J	ND	4
Dissolved Cadmium	NM	10.1E	2.3	2.4	NM	1.9	ND	1.5	NM	9	7.5	NM	ND	ND	ND	4
Total Lead	29.6E	NM	NM	NM	15.3	15.3	17.1	17.1	11.9E	NM	NM	8.2	5.5	5.5	4.1E	5
Dissolved Lead	NM	2.9	10.1E	5.5	NM	2.4E	ND	10.4	NM	45.1	10.1	NM	ND	2.3 J	ND	5
Volatile Organic Compounds (ug/L)																
Total Organics	NM	NM	6	13	20	NM	17.93	5.23	NM	NM	NM	ND	NM	ND	ND	NA

Notes:

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TABLE 2
Historical Data Summary
NL Industries Superfund Site
Pedricktown, New Jersey

Well ID Year	ND			OS			BR							RAO
	1998	2004	2007	1998	2004	2007	1983	1988	1990	1997	1998	2004	2007	
Inorganic Compounds (ug/L)														
Total Cadmium	0.4 B	ND	ND		1.4 J	3.9 J	NM		NM	15.3 J	15	1.3 J	ND	4
Dissolved Cadmium	1.5 B	ND	ND	2.9 B	1.4 J	4.2 J	NM	ND	NM	NM	15	1.4 J	ND	4
Total Lead	ND								NM	1.9 B	ND		ND	5
Dissolved Lead	ND	10.6	ND	6.8 J	94.9	320	NM	5.0 J	NM	NM	1.4 JB	3.9	ND	5
Volatile Organic Compounds (ug/L)														
Total Organics	NM	0.34	0.41	NM	ND	ND	NM	NM	89.3	79	NM	ND	ND	NA

Notes:

NJGWQS = New Jersey Groundwater Quality Standards

NJMCL = New Jersey Maximum Contaminant Level

PQL = Practical Quantitation Limit

* = Original well damaged during the remedial action, replaced in 2004

RAO = Remedial Action Objective. RAO is the lowest value out of NJGWQS, NJMCL, or MCL as defined in the ROD.

ND = Not detected above the laboratories limit of detection (LOD)

NM = Not Measured

NA = Not Applicable

J = Value is approximate

B = Value was lesser than the Contract-required LOD, but greater than the instrument LOD

E = Estimated value based on the presence of an interference

Shaded and bold values indicate an exceedence of the NJGWQS

The 2004 data quality is suspected to have been affected by freezing temperatures during sample collection.

Table 3
Recommended Groundwater Monitoring Locations for MNA Remedy
NL Industries Superfund Site
Pedricktown, New Jersey

Monitoring Well	Well Depth ⁽¹⁾	Screened Interval ⁽²⁾	Aquifer Zone ⁽³⁾	Rationale
BR	39	33-39	UA	western limits
JS	15.37	5-15	UA	eastern limits
JDR	27.26	17-27	UA	eastern limits
KSR	15	5-15	UA	central area
KDR	24	14-24	UA	central area
NS	16.5	6.5-16.5	UA	western limits
ND	24	14-24	UA	western limits
OS	21.3	6.3-21.3	UA	western limits
SS	16.4	6.4-16.4	UA	central area
SD	29.4	17.4-29.4	UA	central area
11	54.1	34.1-54.1	UA	western limits
14	46.6	26.6-46.6	UA	northern limits
15	25	10-25	UA	northern limits
22	16	11-16	UA	eastern limits
23	24	24-34	UA	eastern limits
26	22	12-22	UA	northern limits
27	15	5-15	UA	central area
28	30	20-30	UA	central area
30R	28.71	17-27	UA	central area
31	15	5-15	UA	southern limits
33	10	5-10	UA	northern limits
MW-1 ⁽⁴⁾	TBD	TBD	UA	western limits
MW-2 ⁽⁴⁾	TBD	TBD	UA	western limits

⁽¹⁾ Depth to bottom of well in feet below top of casing (TOC).

⁽²⁾ Screened interval of well in feet below ground surface.

⁽³⁾ UA = Unconfined Aquifer

⁽⁴⁾ Monitoring wells to be installed at locations shown on Fig. 7.

Table 4
Opinion of Probable Cost
(Capital Cost: Monitored Natural Attenuation Groundwater Sampling, One Event)

CAPITAL COST SUMMARY	Quantity	Unit	Unit Cost/Time	Extended Cost	Notes
Groundwater Monitoring					
Labor	1	ea	\$9,000.00	\$9,000	<i>VOC+Tot/Dls pb & cd + WQ = \$500 ea * 28 wells</i>
Analytical Costs	1	ea	\$14,000.00	\$14,000	
Equipment/Expenses	1	ea	\$3,112.00	\$3,112	
			subtotal	\$26,112	
			Remediation/Oversight Costs	\$26,112	
Engineering and Related Costs					
Groundwater Evaluation/Reporting	1	ls	\$5,000	\$5,000	Expect to start in 2008 Costs Included on Table 5 Not Required
Regulatory Interaction	5.00%	ls		\$250	
Contingency	15.00%	%		\$788	
Inflation (3 %, 0 years)	0.00%	%/yrs	1	\$0	
			subtotal	\$6,038	
MNA Work Plan	1	ls	\$0	\$0	Expect to start in 2008 Costs Included on Table 5 Not Required
Regulatory Interaction	10.00%	ls		\$0	
Contingency	0.00%	%		\$0	
Inflation (3 %, 0 years)	3.00%	%/yrs	1	\$0	
			subtotal	\$0	
			Engineering and Related Costs	\$6,038	
TOTAL				\$32,150	

Notes: WQ = Water Quality Parameters

Table 5
Opinion of Probable Cost
(Present Worth: Monitored Natural Attenuation Groundwater Sampling for 30 Years)

Groundwater Monitoring Annual Cost	Qty	Unit	Unit Price	Inflation Rate*	Years of Inflation*	Extended Cost
Groundwater Monitoring Costs						
MNA Work Plan	1	one time only	\$5,000	0.00%	0	\$5,000
Groundwater Monitoring (quarterly)	4	event	\$32,150	0.00%	0	\$128,600
Groundwater Monitoring (semi-annual)	2	event	\$32,150	0.00%	0	\$64,300
Groundwater Monitoring (annual)	1	event	\$32,150	0.00%	0	\$32,150
						\$230,050
Other						
Regulatory Interaction (work plan)	1	ls	\$500	0.00%	0	\$500
Regulatory Interaction (quarterly)**	4	ls	\$3,215	0.00%	0	\$12,860
Regulatory Interaction (semi-annual)**	2	ls	\$3,215	0.00%	0	\$6,430
Regulatory Interaction (annual)**	1	ls	\$3,215	0.00%	0	\$3,215
						\$19,790
						\$249,840
Present Worth Calculation						
Annual Inflation Rate:		Example	2008-2009 Mon.	2010-2012 Mon.	2013-2037 Mon.	
		0.1 (10% inflation)	0.03	0.03	0.03	
Discount or Interest Rate: (annual compounding)		0.08 (8% interest rate)	0.05	0.05	0.05	
Annual Cost Throughout Current Year (cost of activities performed in current year not adjusted for inflation during current year)		\$100 (Estimated 1998 cost)	\$146,960	\$70,730	\$35,365	
Current Year		2003	2007	2007	2007	
Year of First End-of-Year Payment		2005	2008	2010	2013	
Year of Last End-of-Year Payment		2013	2009	2012	2037	
Present Worth (Beginning of Current Year)		\$1,006	\$285,576	\$196,503	\$631,458	
TOTAL PRESENT WORTH	\$1,113,537					

NOTES:

- * If a unit rate is derived from a previous cost estimate, then it is adjusted for inflation to 2007 dollars. If the unit rate is based on current costs, then there is no adjustment for inflation.
 ** Estimated at 10% of One Monitoring Event cost.

Table 6
Treatability Study Data Summary for the April 2007 Monitoring Well Sampling
NL Industries Superfund Site
Pedricktown, New Jersey

Parameter	Well Number												
	102	31	103	104	105	106	107	108	109	110	111	112	113
Inorganics													
Alkalinity (mg/L)	49	50	2	10	2	22	38	2	100	2	2	15	48
BOD (mg/L)	2	2	2	2	2	2	2	2	2	2	2	2	2
Chloride (mg/L)	4	4	7	3	7	6	43	3,000	2	49	3	37	44
COD (mg/L)	5	5	7	5	5	8	22	250	9	13	5	5	9
Calcium - dissolved (ug/L)	35,100	34,600	15,500	8,590	12,500	27,100	51,200	209,000	39,200	81,900	18,600	78,200	15,300
Calcium - total (ug/L)	38,200	31,300	11,800	8,370	11,600	24,700	47,500	199,000	36,700	78,600	16,500	72,200	14,000
Manganese - dissolved (ug/L)	81	61	437	30	675	231	518	8,170	7.0 J	3,830	110	2,210	2,580
Manganese - total (ug/L)	106	100	340	31	672	220	479	8,020	34	3,780	99	2,240	7,780
Iron - dissolved (ug/L)	709	474	1,890	267	114	7,710	23,400	294,000	18.8 U	77,500	18.8 U	18.8 U	27,500
Iron - total (ug/L)	3,150	2,910	2,700	736	344	7,830	23,200	287,000	1,420	76,300	423	19	N/A
Sulfate (mg/L)	46	41	220	17	210	220	110	9,800	41	4,600	86	780	16
Sulfide (mg/L)	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Organics													
TOC (mg/L)	3.12	3.11	3.76	2.56	1.37	4.46	11	26	4.9	4.08	1.58	0.4	5.19

J = Data indicates the presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The concentration given is an approximate value.

U = Parameter was flagged in data validation because of laboratory contamination and are considered non-detects.

* 102 is a duplicate sample obtained from monitoring well 31.

N/A = Not Analyzed

ND = Non Detect

Table 7
Opinion of Probable Cost
(pH Adjustment, Reagent Injection and Injection Point Installation Capital Costs)

Capital Cost Summary	Quantity	Unit	Unit Cost/Time	Extended Cost	Notes
<u>Remediation Costs</u>					
Mobilization	1	ls	\$2,000.00	\$2,000	Average 20 feet deep tanks, tubing, pumps NaOH application (approx. 5,000 lbs) cd vol = 25 mill gall/1000 gal * \$5 2 people @ \$150/hr, one 10 hr day
Injection Pt Installation	12	ea	\$3,000.00	\$36,000	
Reagent Injection Equipment	1	ls	\$7,500.00	\$7,500	
pH Neutralization (one event)	1	ls	\$2,000.00	\$2,000	
Reagent Chemicals (quarterly for 1 year)	4	ea	\$125,000.00	\$500,000	
Labor for reagent injection/pH neutralization	5	ea	\$1,500.00	\$7,500	
			subtotal	\$555,000	
Oversight, Injection pt Installation	7	day	\$1,000	\$7,000	10% of Remediation subtotal.
Regulatory Interaction	10.00%	ls		\$55,500	
			subtotal	\$62,500	
Contingency	30.00%	%		\$185,250	
Inflation (3 %, 1 years)	3.00%	%/yrs	1	\$24,083	
			subtotal	\$209,333	
	Remediation/Oversight Costs			\$826,833	Expect to perform in 2008 to 2009
<u>Engineering and Related Costs</u>					
Pilot Study + Work Plan	1	ls	\$50,000	\$50,000	Expect to perform in 2008
Regulatory Interaction	10.00%	ls		\$5,000	
Contingency	30.00%	ls		\$16,500	
Inflation (3 %, 1 years)	3.00%	%/yrs	1	\$2,145	
			subtotal	\$73,645	
Remedial Action Plan	1	ls	\$10,000	\$10,000	Plan for implementation of alternative 10% of plan cost.
Regulatory Interaction	10.00%	ls		\$1,000	
Contingency	30.00%	%		\$3,300	Expect to perform in 2008-2009
Inflation (3 %, 1 years)	3.00%	%/yrs	1	\$429	
			subtotal	\$14,729	
	Engineering and Related Costs			\$88,374	
TOTAL				\$915,207	

Table 8
Opinion of Probable Cost
(Present Worth: Reagent Injection)

Present Worth Calculation	Example	2008 Eng.	2009 Ram/Ovst
Annual Inflation Rate:	0.1 (10% inflation)	0.03	0.03
Discount or Interest Rate: (annual compounding)	0.08 (8% interest rate)	0.05	0.05
Annual Cost Throughout Current Year (cost of activities performed in current year not adjusted for inflation during current year)	\$100 (Estimated 1998 cost)	\$88,374	\$826,833
Current Year	2003	2007	2007
Year of First End-of-Year Payment	2005	2008	2009
Year of Last End-of-Year Payment	2013	2008	2009
Present Worth (Beginning of Current Year)	\$1,006	\$86,691	\$795,635
TOTAL PRESENT WORTH	\$882,325		

NOTES:

* If a unit rate is derived from a previous cost estimate, then it is adjusted for inflation to 2007 dollars. If the unit rate is based on

** Estimated at 10% of Operation and Maintenance cost.

Table 9
Opinion of Probable Cost
(Capital Cost: Permeable Reaction Barrier Construction Costs)

CAPITAL COST SUMMARY	Quantity	Unit	Unit Cost/Time	Extended Cost	Notes
PRB Construction					
Labor	1	ea	\$972,000.00	\$972,000	Laborers, operators and supervisors Approx. 150 days in construction Approx 71,000 CF of Apatite II = \$1.35 million Includes Mob/Demob
Equipment	1	ea	\$500,750.00	\$500,750	
Materials	1	ea	\$2,560,000.00	\$2,560,000	
Admin Requirements	1	ea	\$508,000.00	\$508,000	
			subtotal	\$4,540,750	
			Remediation/Oversight Costs	\$4,540,750	
Oversight Costs					
Construction Total	1	ls	\$4,540,750	\$4,540,750	Not included in estimate
Regulatory Interaction	5.00%	ls		\$227,038	
Contingency	30.00%	%		\$1,430,336	
Inflation (3 %, 1 years)	3.00%	%/yrs	0	\$0	
			subtotal	\$6,198,124	Expect to start in 2009
Remedy Design	1	ls	\$50,000	\$50,000	Costs provided in 2009 dollars
Regulatory Interaction	5.00%	ls		\$2,500	
Contingency	30.00%	%		\$15,750	
Inflation (3 %, 0 years)	3.00%	%/yrs	0	\$0	
			subtotal	\$68,250	
		Total		\$6,266,374	

Table 10
ALTERNATIVE COMPARISON MATRIX
NL INDUSTRIES SITE, PEDRICKTOWN, NJ

Evaluation Criteria	Remedial Alternatives				
	No Action	MNA	Reagent Injection	Permeable Reaction Barriers	Pump and Treat
Overall Protection of Human Health and the Environment	Protective with application of institutional controls restricting groundwater access.	Same as no action.	Most protective alternative based upon relatively short projected period to achieve RAOs.	No more effective than no action.	No more effective than no action.
Compliance With ARARs	Compliant over long-term, assuming continuation of natural attenuation processes.	Same as no action.	Compliant with NJQSSs in short time frame (1-5 yrs). No other ARARs apply.	No more effective than no action.	No more effective than no action.
Long-Term Effectiveness and Permanence	Effective and permanent, assuming continuation of natural attenuation processes.	Same as no action.	Very effective and permanent.	No more effective than no action.	No more effective than no action.
Reduction of Toxicity, Mobility and Volume	Acceptable over long-term. Constituents are not mobile. Volume reduction through natural attenuation.	Same as no action.	Will reduce toxicity and volume to negligible concern within approximately 5 year timeframe.	No more effective than no action.	No more effective than no action.
Short-Term Effectiveness	Poor short-term effectiveness.	Same as no action.	Effective	No more effective than no action.	No more effective than no action.
Implementability	Excellent	Excellent	Excellent. Will require pilot study to optimize and verify period to achieve RAOs.	Can be constructed, but not effective.	System construction is feasible, but not effective.
Cost	Moderate costs associated with implementation of institutional controls and administrative costs.	Approx. \$1,113,537 for thirty year monitoring program and work plan.	Approximately \$882,325 plus groundwater monitoring costs (approx. \$650,000 for 10 years).	Approximately \$6,266,374 for construction of PRB + \$2,000,000 for O&M every 3-5 years + groundwater monitoring for 30 years (approx. \$1,100,000)	Cost estimated at \$10.1 million in 1993 [O'Brien & Gere, 1993]. CSI currently estimates construction cost at approximately \$3 million.
State/EPA Acceptance	Institutional controls for an extended period may be undesirable.	Becoming more widely accepted by regulators for inorganics in groundwater, institutional controls required.	Attainable assuming technical demonstration is favorable via pilot study.	Technology is widely accepted by regulatory community pending technical feasibility.	Widely accepted by regulatory community and ROD prescribed remedy for groundwater.
Community Acceptance	Institutional controls for extended period may be undesirable.	Same as no action.	Acceptable to community for potential short cleanup time, minimal construction and no Instit. Controls.	Extensive construction activity and poor effectiveness is not likely to be perceived favorably by local community.	Poor effectiveness compared to cost. Intrusive activity required is not likely to be perceived favorably by local community.

APPENDIX A
Table F from 1994 Record of Decision

TABLE F
NL INDUSTRIES SITE
GROUND WATER ARARS

<u>HAZARDOUS CONTAMINANT</u>	<u>NJMCL¹</u>	<u>NJGWQS²</u>	<u>PQL³</u>	<u>MCL⁴</u>
<u>Organic (ppb)</u>				
Acetone	-	700	NA	-
Bis-(2-ethylhexyl)phthalate	4	3	30	-
Chloroform	-	6	1	-
1,2-Dibromomethane	-	-	-	-
1,1-Dichloroethane	-	70	-	-
1,1-Dichloroethylene	2	1	2	7
1,2-Dichloropropane	5	0.5	1	5
Ethylbenzene	700	700	5	700
Naphthalene	-	-	-	-
N-Nitroso-di-n-propylamine	-	0.005	20	-
Tetrachloroethylene	1	0.4	1	5
Toluene	1,000	1,000	5	1,000
1,1,1-Trichloroethane	26	30	1	200
1,2,4-Trimethylbenzene	-	-	-	-
1,3,5-Trimethylbenzene	-	-	-	-
Vinyl Chloride	2	0.08	5	2
Xylene(s) (total)	44	40	2	10,000
o-		NA	1	-
m&p-		NA	2	-

¹New Jersey Maximum Contaminant Levels (NJMCLs) are expressed in ppb. (N.J.A.C. 7:10-16.7) For any listed contaminant, the more stringent of the NJMCL, NJGWQS, or federal MCL applies.

²New Jersey Ground Water Quality Standards (NJGWQS) (N.J.A.C. 7:9-6) are expressed in parts per billion (ppb).

³The Practical Quantitation Levels (PQLs) are expressed in ppb. In accordance with N.J.A.C. 7:9-6.9(c), where a constituent standard (the criterion adjusted by the antidegradation policy and applicable criteria exemptions) is of a lower concentration than the relevant PQL, the Department shall not (in the context of an applicable regulatory program) consider the discharge to be causing a contravention of that constituent standard so long as the concentration of the constituent in the affected ground water is less than the relevant PQL.

⁴Federal Maximum Contaminant Levels (MCLs) are expressed in ppb. For any listed contaminant, the more stringent of the federal MCL, NJMCL, and the NJGWQS applies.

TABLE F (Cont'd)
NL INDUSTRIES SITE
GROUND WATER ARARS

<u>HAZARDOUS CONTAMINANT</u>	<u>NJMCL¹</u>	<u>NJGQS²</u>	<u>PQL³</u>	<u>MCL⁴</u>
<u>Metals (ppb)</u>				
Antimony	6	2	20	6
Arsenic (total)	50	0.02	8	50
Beryllium	4	0.008	20	4
Cadmium	5	4	2	5
Chromium (total)	100	100	10	100
Copper	1,300*	1,000	1,000	-
Cyanide	200	200	40	200
Lead (total)	15*	5	10	-
Mercury (total)	2	2	0.5	2
Nickel (soluble salts)	100	100	10	100
Selenium (total)	50	50	10	50
Silver	-	NA	2	-
Thallium	2	0.5	10	2
Zinc	-	5,000	30	-
<u>Radiation (see footnotes 4 & 5 for units)</u>				
Gross Alpha	15 ⁵	15 ⁵	-	15 ⁵
Gross Beta	4 ⁶	4 ⁶	-	4 ⁶

* New Jersey Action Level

⁵Federal MCL expressed in picocuries/liter (pCi/l). From 40 CFR part 141.

⁶Federal MCL expressed in picocuries/liter (pCi/l). From 40 CFR part 141.

APPENDIX B
Core Laboratory Report (Thin Section
Petrography and X-Ray Diffraction, October
1998)



CORE LABORATORIES

**PETROGRAPHIC ANALYSES
FOR
GEOSYNTEC CONSULTANTS
SOIL SAMPLES
NL INDUSTRIES PROJECT**

**File 198178
October 1998**

**Performed by:
Core Laboratories, Advanced Technology Center
Reservoir Geology/Stratigraphy Group
1875 Monetary Lane
Carrollton, Texas 75006
U.S.A.
(972) 466-2673**



RECEIVED 10 29 1998

PETROLEUM SERVICES

October 29, 1998

Jeff Moore
GeoSyntec Consultants
10015 Old Columbia Rd., Ste. A-200
Columbia, Maryland 21046

Subject: Petrographic Analyses
Sample Type: Sand Soils
Location: NL Industries, Pedricktown, New Jersey
File Number: 198178

Dear Mr. Moore:

The enclosed study includes detailed thin section petrography and X-ray diffraction (XRD) analyses of four soil samples from NL Industries, Pedricktown, New Jersey. The main focus of this report is to document the presence or absence of any mineral matrices in the samples that may contain lead-bearing substances. A secondary focus of the report is to document the possible detection of lead-bearing substances. Table 1 shows the XRD data, and Table 2 contains the point-count results. Plates 1 through 4 display the thin section photomicrographs and descriptions. Two original copies of this report were prepared. You have received one report, and the other was sent to your colleague, Hal Tuchfeld, in California.

Thank you for selecting Core Laboratories to perform these analyses for GeoSyntec Consultants. Please feel free to contact us if you have any questions or comments concerning this report, or if we can be of further service.

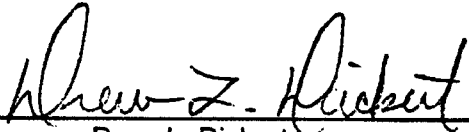
Sincerely,


Drew L. Dickert
Senior Petrologist
Reservoir Geology/Stratigraphy Group
(972) 323-3998

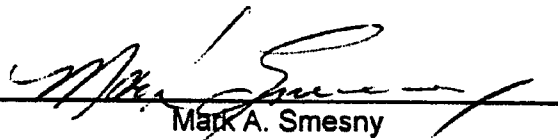
Core Laboratories, Inc.

1875 Monetary Lane, Carrollton, Texas 75006-7012, (972) 466-2673, Fax (972) 323-3930, E-mail @corelabusa.com

PROJECT TEAM


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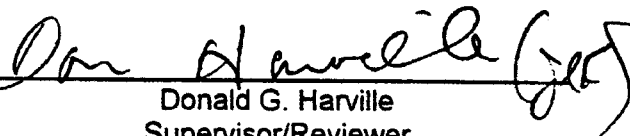

Donald G. Harville
Supervisor/Reviewer

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DISCUSSION

Introduction

Core Laboratories' Reservoir Geology/Stratigraphy Group, Carrollton, Texas, performed a petrographic study on four soil samples from NL Industries, Pedricktown, New Jersey. The analyses performed were detailed thin section petrography (includes a point-count of 250 points) and bulk & clay X-ray diffraction (XRD). The purposes of this study are to describe the natural soil texture and composition, document the presence or absence of any mineral matrices in the samples that may contain lead-bearing substances, and identify any lead-bearing substances, if possible. Table 1 shows the XRD data, and Table 2 contains the point-count results. Plates 1 through 4 display the thin section photomicrographs and descriptions. The following discussion summarizes the findings. For ease of reference in the discussion, the sample names have been shortened to SV26, SV28, SV29, and SV40.

Sample Descriptions

The thin section analysis shows that all four soil samples are poorly sorted sands. SV26, SV28, and SV40 are silty sands, in which at least ten percent of the grains are silt sized. SV29 is a muddy sand, where clay matrix and silt together compose over ten percent of the sample. The muddy sand has the finest estimated average grain size (0.28 mm, excluding clay matrix), whereas the other sands have estimated average grain sizes between 0.36 and 0.40 millimeters. Most of the grains in each sample range from <0.01 to 2.5 millimeters in diameter. No pebbles (grains >4 mm) are present in the thin sections; however, traces of pebbles were noted in the jars containing SV26 and SV28, and minor amounts of pebbles in the SV40 sample jar. The individual grain shapes in each sample range from rounded to angular. Subrounded and subangular grains are predominant. Angular grains are mostly concentrated in the finer grain size fractions. Samples SV29 and SV40 seem to contain greater amounts of rounded grains than the other two samples. Grain compaction and natural pore systems could not be assessed, because these sands are unconsolidated and disaggregated in the thin sections. The uneven distribution of silt, clays, and heavy minerals in SV26, SV28, and SV40 could be wholly the result of sample preparation, or it may indicate the presence of some disrupted lamination.

The soil composition was measured two different ways. XRD analysis (Table 1) shows that three of the samples (SV 26, SV28, and SV40) contain 96 to 99 percent quartz, with small amounts of feldspars and clays. Sample SV29 contains only 83 percent quartz by XRD, with 11 percent clays and 5 percent feldspars. Point-count analysis (Table 2) shows similar proportions of quartz, feldspars, and clays, compared to Table 1. Most of the quartz occurs as individual mono- and poly-crystalline grains. The minor metamorphic rock fragments (0.4 – 2.4%) are mostly metaquartzites. Traces of quartz overgrowth cement are found on some grains (Plate 1B). Some of these overgrowths probably formed in-situ, but others may be relics from a recycled sandstone source. Small amounts of heavy minerals (magnetite/ilmenite, tourmaline, zircon, hornblende, etc.) and glauconite grains are also found in every sample. The muddy sand (SV29, Plate 3) contains common clay matrix. Samples SV28 and SV40 contain minor amounts of clay matrix, 2 percent and 3 percent by XRD, respectively. The thin

sections also reveal a little more clay in SV40 than SV28, although this is not reflected in the point-count results because of the highly uneven distribution of clays in SV40. The clay minerals are mostly detrital, but they appear to be partially altered and recrystallized. XRD results reveal that the clay fractions consist of 60 to 78 percent kaolinite and 22 to 40 percent illite/mica (includes sericite). Tiny crystals and coatings of iron oxide and titanium oxide represent 1.2 to 4.0 percent of the thin sections by point-count. Traces of organic grain coatings are present in one sample (SV29). Rare amounts of dolomite occur within a few quartz grains (SV26 and SV28). XRD detected possible traces of lead phosphate in SV28 and SV40.

Conclusions

The main purpose of this study was to document the presence or absence of any mineral matrices that may contain lead compounds that could be interpreted to be contaminants from the seeping of lead-bearing fluids into the soil. As a secondary purpose, any lead-bearing substances detected were to be identified.

Some of the quartz and feldspar grains show signs of leaching (pitted grains; Plates 1A & 4A), but this can be present in natural soils and does not necessarily indicate damage from contaminating fluids. The thin sections reveal no mineral grains or crusts that are composed principally of lead compounds. Using polarized and reflected light microscopy, the minor amounts of dark coatings on grains and tiny crystals in the clay matrix (Plates 1-4B) are identified as mostly iron and titanium oxides. Many of these crystals are so small (<1-3 microns) that they cannot be adequately identified in thin section. If any lead compounds or elemental lead are present, they should be associated with these tiny crystals and the oxide coatings. Clay aggregates of kaolinite and illite/mica may be able to adsorb lead onto the clay crystal surfaces; however, these clay types are not noted for absorption of elements into their crystal structures.

The traces of lead phosphate reported by XRD in SV28 and SV40 are based on one peak in the diffraction pattern matching the primary peak for lead phosphate. In XRD analysis, separate mineral phases are recognized by distinct diffraction patterns containing a primary peak and secondary peaks for each mineral. The secondary peaks of some minerals can overlap primary peaks of other minerals. Also, relative peak heights are related to mineral concentration, and the secondary peaks for minerals present in small quantities are not generally detectable. Even the primary peaks for trace minerals are sometimes difficult to resolve from background noise. The peak identified to be a primary peak for lead phosphate does not seem to correspond to a secondary peak of any other component in the sample (if it did, the interpretation of lead phosphate would not be justified). Thus, the presence of small amounts of lead phosphate is a possibility, even though a distinct diffraction pattern for this compound is lacking (no secondary peaks). If lead phosphate is indeed present, one would expect it to be most prevalent in SV29, where clay matrix and iron and titanium oxide coatings are most common, but XRD does not show traces of lead phosphate for this sample.

This thin section and XRD study shows that mineral matrices that may contain lead-bearing substances are present. However, lead compounds, if present, are rare in these soil samples. These analyses are not sufficiently sensitive to completely affirm or deny the presence of rare amounts of lead in these samples.

ANALYTICAL PROCEDURES

Thin Section Preparation

Sample fractions are prepared for thin section analysis by first impregnating them with epoxy to augment sample cohesion and to prevent loss of materials during grinding. A blue dye was added to the epoxy to highlight the pore spaces. Each sample was mounted on a frosted glass slide and then cut and ground in water to an approximate thickness of 30 microns. The thin sections were examined using standard petrographic techniques.

X-ray Diffraction Analysis

X-ray diffraction analysis provides the identification and quantification of the rock-forming minerals present in the formation. Samples selected for bulk and clay X-ray diffraction analysis were dried and cleaned of obvious contaminants. Each sample was dried, weighed, placed in water and treated with a sonic cell disrupter. The resultant slurries were centrifuged to fractionate each fraction at 4 microns. The suspended <4 micron fraction was decanted and saved. The >4 micron fraction was dried and weighed to determine the percent of clay- and silt-sized materials. The suspended <4 micron fraction was suctioned onto a pure silver substrate to orient the clay-sized particles. The <4 micron fraction was analyzed in an air-dried state and then treated with ethylene glycol vapor for 24 hours and re-analyzed. The >4 micron fraction was milled and scanned on an X-ray diffractometer. The samples selected for bulk analysis only were also milled and scanned on the diffractometer. The resulting diffractograms were then analyzed for mineral content using a profile-fitting algorithm. The integrated areas from the profile-fitting algorithm were entered into a spreadsheet that contains correction coefficients for numerous minerals. These coefficients were obtained according to the adiabatic method outlined by Chung (1974a, 1974b, 1974c). The tabular data are reported in a weight percent format in Table 1.

REFERENCES

- Chung, F.H. (1974) A new X-ray diffraction method for quantitative multicomponent analysis. *Advances in X-ray Analysis*, 17, 106-115.
- Chung, F.H. (1974) Quantitative interpretation of X-ray diffraction patterns of mixtures. I. Matrix-flushing method for quantitative multicomponent analysis. *Journal of Applied Crystallography*, 7, 519-525.
- Chung, F.H. (1974) Quantitative interpretation of X-ray diffraction patterns of mixtures. II. Adiabatic principle of X-ray diffraction analysis of mixtures. *Journal of Applied Crystallography*, 7, 526-531.
- Folk, R.L. (1980) *Petrology of Sedimentary Rocks*. Hemphill Publishing Company, Austin, Texas, 184p.

Whole Rock Composition (weight %)												Relative Clay Abundance (Normalized to 100%)				
Sample ID	Depth	Quartz	K feldspar	Plagioclase	Calcite	Dolomite	Siderite	Pyrite	Pb phosphate	Hematite	Total Clays	Illite/Mica	Kaolinite	Chlorite	Smectite	Illite/Smectite
SV26 7/20/88	14-16	99	0	Tr	0	Tr	0	0	0	0	1	31	69	0	0	0
SV28 7/16/88	12-16	96	1	1	0	Tr	0	0	Tr	0	2	40	60	0	0	0
SV29 7/15/88	10-16	83	3	2	0	1	0	0	0	Tr	11	22	78	0	0	0
SV-40	N/A	96	0	Tr	0	1	0	0	Tr	0	3	38	64	0	0	0

CORE LABORATORIES

Point-Count Tally Sheet

GeoSyntec Consultants
Sand Soil Samples
NL Industries Project

C.L. File No: 198178
Date: 27-Oct-98
Petrologist: D. Dickert

Table 2
Modal Percent

Sample ID		SV26	SV28	SV29	SV40
Quartz:	Monocrystalline	74.0	80.8	61.6	76.0
	Polycrystalline	17.6	10.8	7.2	17.2
	Total	91.6	91.6	68.8	93.2
Feldspars:	K-Feldspar	0.4	0.8	2.4	1.2
	Plagioclase	tr	tr	1.6	tr
	Total	0.4	0.8	4.0	1.2
Rock Fragments:	Crystalline Igneous		tr	0.8	tr
	Sedimentary	0.4	tr	4.0	0.4
	Metamorphic	1.2	0.8	2.4	0.4
	Chert/Chalcedony	tr	1.2	0.4	0.4
	Total	1.6	2.0	7.6	1.2
Accessory:	Biotite	tr		tr	tr
	Muscovite	tr	tr	1.6	tr
	Magnetite/Ilmenite	1.2	tr	0.4	0.4
	Tourmaline	0.4	tr	0.4	tr
	Zircon	tr	0.4	tr	tr
	Hornblende	tr	tr	0.4	tr
	Sphene	0.4		tr	
	Other Heavy Minerals	tr	tr	0.4	tr
	Glauconite	0.8	tr	0.4	tr
	Organic Debris	tr			
	Total	2.8	0.4	3.6	0.4
Matrix:	Detrital Clay	0.4	2.8	10.8	2.4
	Pseudomatrix				
	Total	0.4	2.8	10.8	2.4
Clays: (Authigenic)	Kaolinite	tr	tr		tr
	Chlorite		tr	tr	tr
	Sericite	tr	tr	tr	tr
	Undiff. Illite/Smectite	0.8	0.4	tr	0.4
	Total	0.8	0.4		0.4
Non-Clay Cements:	Quartz Overgrowths	0.8	0.4	0.8	tr
	Feldspar Overgrowths				
	Dolomite	tr	tr		
	Pyrite				
	Iron Oxide	0.8	0.4	2.4	tr
	Titanium Oxide	0.8	1.2	1.6	1.2
	Organic Coatings			0.4	
	Total	2.4	2.0	5.2	1.2
Porosity:	Not counted - disaggregated samples				
	Total				
Grand Total		100.0	100.0	100.0	100.0

THIN SECTION PETROGRAPHY

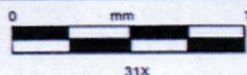


Plate 1A

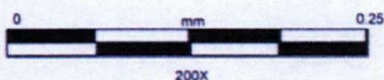
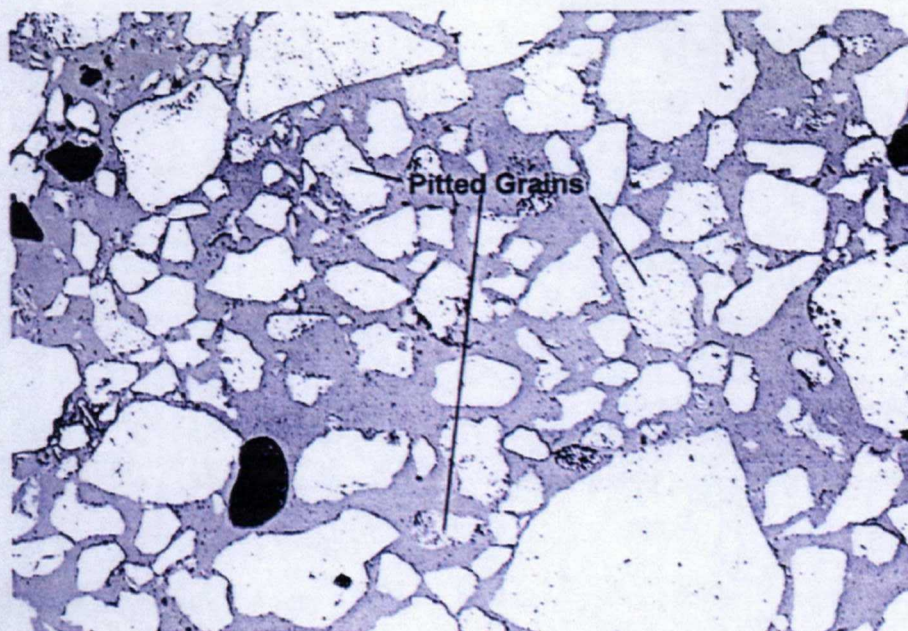
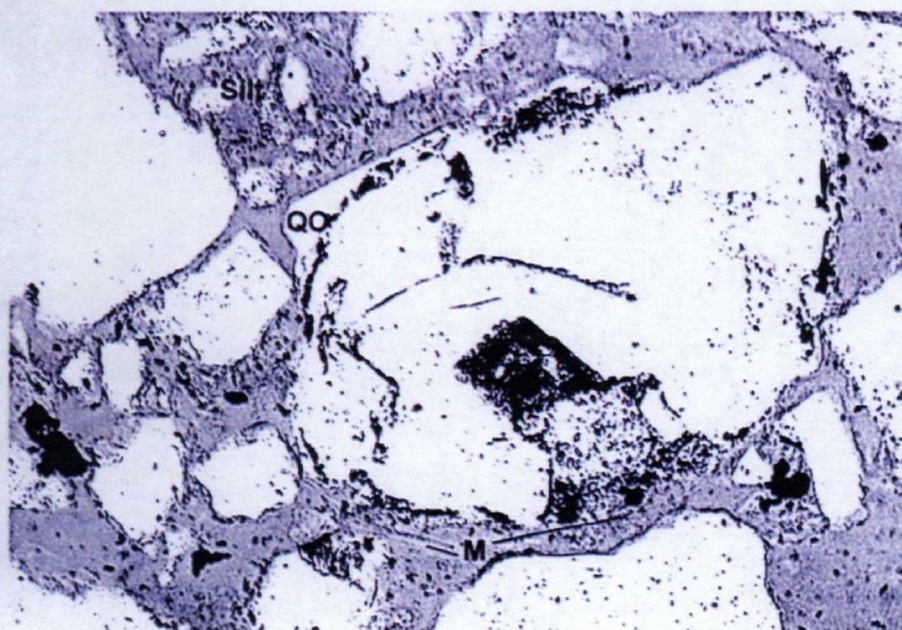


Plate 1B



GeoSyntec Consultants
Soil Samples
NL Industries Project
Sample: SV26072098
Depth: 14 - 16 feet

Soil Type & Texture

Classification (Folk)	Silty sand
Grain Size (mm)	Range = <0.01 - 2.54
(estimated)	Avg. = 0.40 (med. sand)
Grain Sorting	Poor
Grain Roundness	Rounded to angular
Compaction	Disaggregated
Structures	None evident

Composition (%)

Detrital Grains	Detrital Matrix
Mono. Qtz.	74.0 Clay 0.4
Poly. Qtz.	17.6 Authigenic Clay
K-feldspar	0.4 Kaolinite tr
Plagioclase	tr Chlorite
Igneous R.F.	Sericite tr
Sedim. R.F.	0.4 Undiff. I/S 0.8
Meta. R.F.	1.2 Cements (non-clay)
Chert	tr Quartz O.G. 0.8
Biotite	tr Feld. O.G.
Muscovite	tr Dolomite tr
Heavy Min.	2.0 Pyrite
Glaucanite	0.8 Iron Oxide 0.8
Organics	tr TiO ₂ 0.8
	Organic

Photomicrograph Captions

Plate 1A: This soil sample consists of poorly sorted, silty sand. The white grains are nearly all quartz, but with small amounts of feldspar (mostly K-feldspar). Black grains in the upper-left and upper-right corners of the photo are magnetite/ilmenite. The well rounded, green grain in the lower-left quadrant is glauconite. Some quartz is slightly dissolved (pitted grains), as evidenced by traces of blue epoxy within the grains.

Plate 1B: A high-magnification view of the sample reveals dark-colored coatings on some grains and dark specks between grains. These dark brown to black materials are mostly iron oxide (hematite) and titanium oxide. No lead compounds are identified; however, traces of lead compounds may be associated with these dark crusts and specks. A quartz overgrowth (QO) is observed on top of a hematite grain coating. Tiny white grains between the larger grains are mainly quartz silt, along with small amounts of muscovite/sericite flakes (M).

CORELAB

Core Laboratories

THIN SECTION PETROGRAPHY



Plate 2A

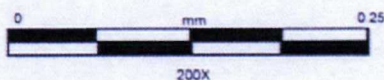
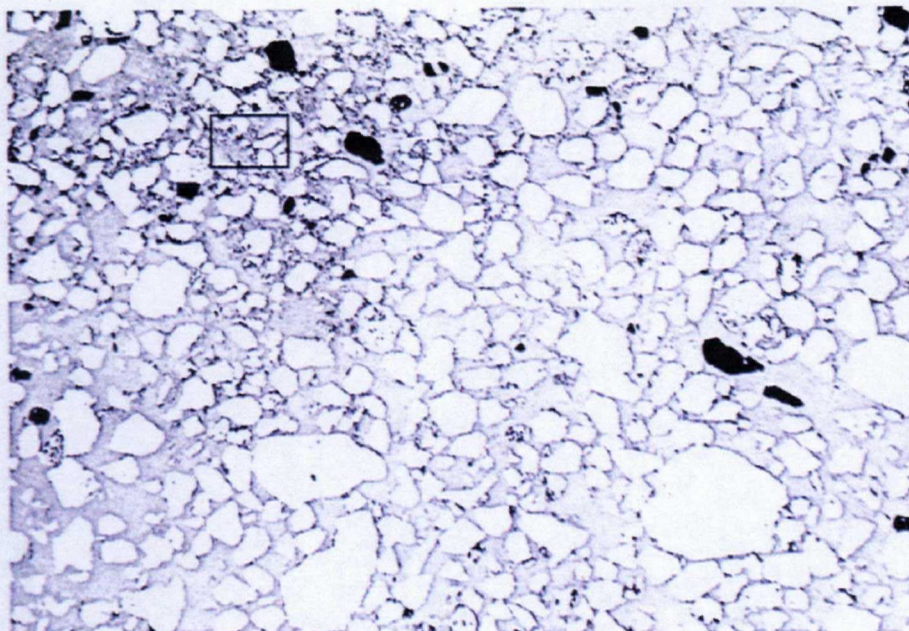
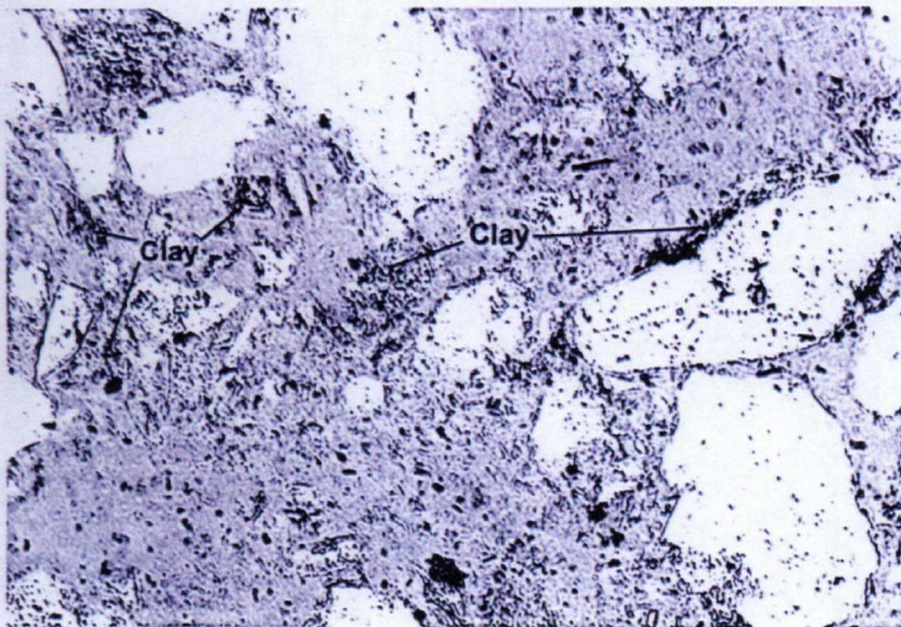


Plate 2B



GeoSyntec Consultants
Soil Samples
NL Industries Project
Sample: SV28071698
Depth: 12 - 16 feet

Soil Type & Texture

Classification (Folk)	Silty sand
Grain Size (mm)	Range = <0.01 - 2.18
(estimated)	Avg. = 0.38 (med. sand)
Grain Sorting	Poor
Grain Roundness	Rounded to angular
Compaction	Disaggregated
Structures	None evident

Composition (%)

Detrital Grains		Detrital Matrix	
Mono. Qtz.	80.8	Clay	2.8
Poly. Qtz.	10.8	Authigenic Clay	
K-feldspar	0.8	Kaolinite	tr
Plagioclase	tr	Chlorite	tr
Igneous R.F.	tr	Sericite	tr
Sedim. R.F.	tr	Undiff. I/S	0.4
Meta. R.F.	0.8	Cements (non-clay)	
Chert	1.2	Quartz O.G.	0.4
Biotite		Feld. O.G.	
Muscovite	tr	Dolomite	tr
Heavy Min.	0.4	Pyrite	
Glaucanite	tr	Iron Oxide	0.4
Organics		TiO ₂	1.2
		Organic	

Photomicrograph Captions

Plate 2A: This sample is very similar to the previous sample (Plate 1). A lower magnification is provided here, compared to Plate 1A, so that the silty texture of the sand is better observed (upper-left quadrant). Scattered dark grains are heavy minerals. The blackest grains are magnetite/ilmenite.

Plate 2B: The area within the black rectangle in Plate 2A is presented in this photomicrograph. The main difference between this sample and SV26072098 is that this sample contains greater (although minor) amounts of clay matrix (yellowish green). This intergranular to grain-coating clay contains many tiny specks of titanium and iron oxides (black). Some of this micron-sized material may include lead compounds, but this cannot be established with thin section analysis. XRD analysis reveals that the clays in this sample are kaolinite and illite/mica.

THIN SECTION PETROGRAPHY

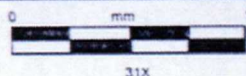


Plate 3A

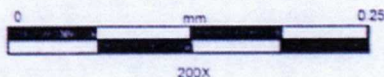
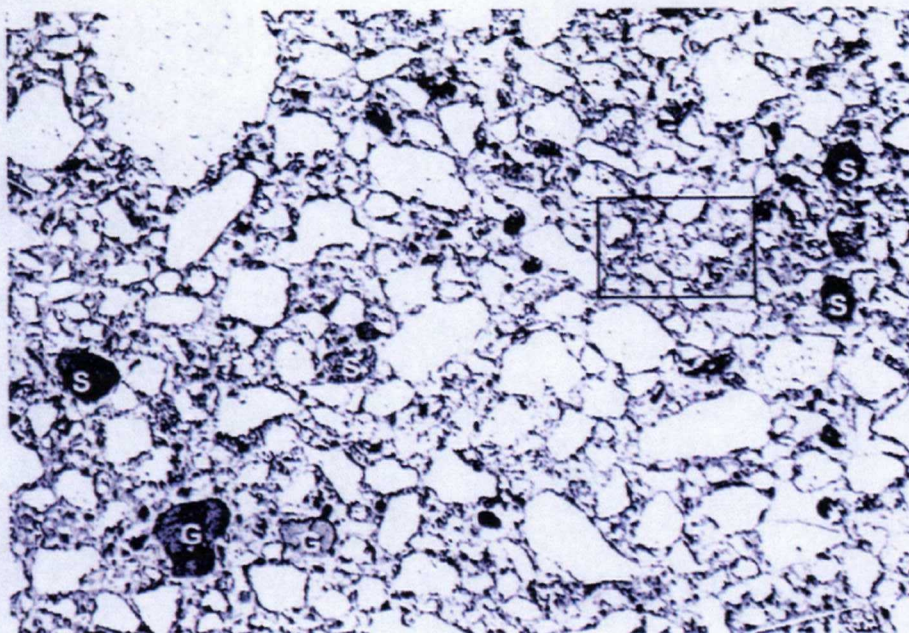
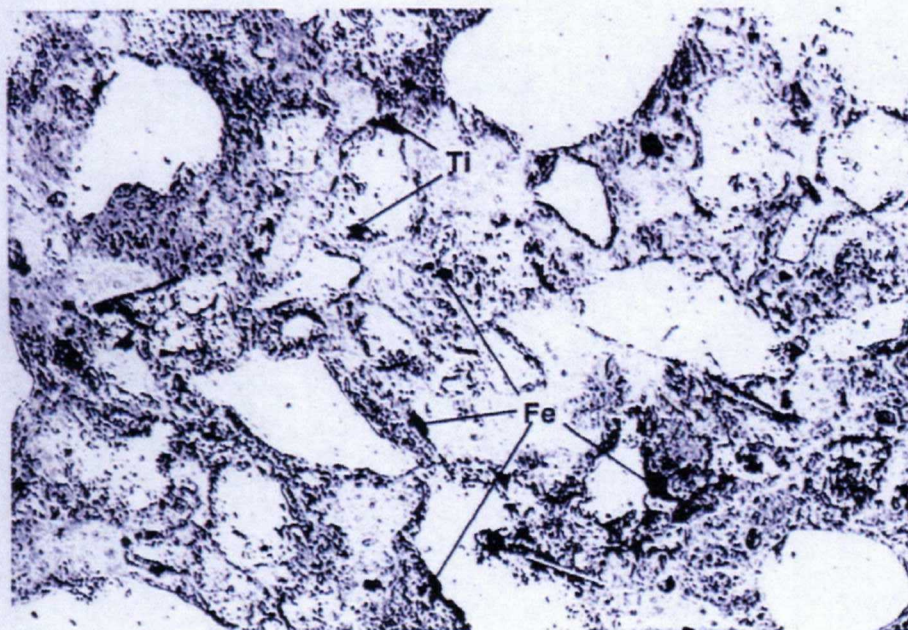


Plate 3B



GeoSyntec Consultants
Soil Samples
NL Industries Project
Sample: SV29071598
Depth: 10 - 16 feet

Soil Type & Texture

Classification (Folk)	Muddy sand
Grain Size (mm)	Range = <0.01 - 2.02
(estimated)	Avg. = 0.28 (med. sand)
Grain Sorting	Poor
Grain Roundness	Rounded to angular
Compaction	Disaggregated
Structures	None evident

Composition (%)

Detrital Grains		Detrital Matrix	
Mono. Qtz.	61.6	Clay	10.8
Poly. Qtz.	7.2	Authigenic Clay	
K-feldspar	2.4	Kaolinite	
Plagioclase	1.6	Chlorite	tr
Igneous R.F.	0.8	Sericite	tr
Sedim. R.F.	4.0	Undiff. I/S	tr
Meta. R.F.	2.4	Cements (non-clay)	
Chert	0.4	Quartz O.G.	0.8
Biotite	tr	Feld. O.G.	
Muscovite	1.6	Dolomite	
Heavy Min.	1.6	Pyrite	
Glauconite	0.4	Iron Oxide	2.4
Organics		TiO ₂	1.6
		Organic	0.4

Photomicrograph Captions

Plate 3A: This is a poorly sorted, muddy sand sample. It is classified as muddy because of the common amounts of silt and clay occurring between the predominant sand grains. The white grains are mostly quartz, with minor amounts of K-feldspar and plagioclase. Various sedimentary argillaceous rock fragments (S) appear dark. Glauconite (G) grains are also noted. The one on the left appears orange due to oxidation.

Plate 3B: The area within the black rectangle in Plate 3A is shown. This sample contains common amounts of clay matrix (greenish brown). This clay coats grains and fills pores. It consists of 78% kaolinite and 22% illite/mica, according to XRD analysis. Within the clay are dark-colored coatings and crystalline specks that are predominantly iron (Fe) and titanium (Ti) oxides. Micron-sized particles of lead compounds may possibly also be present within the clays and oxide coatings.

THIN SECTION PETROGRAPHY

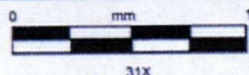


Plate 4A

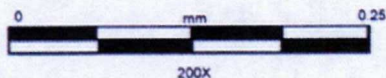
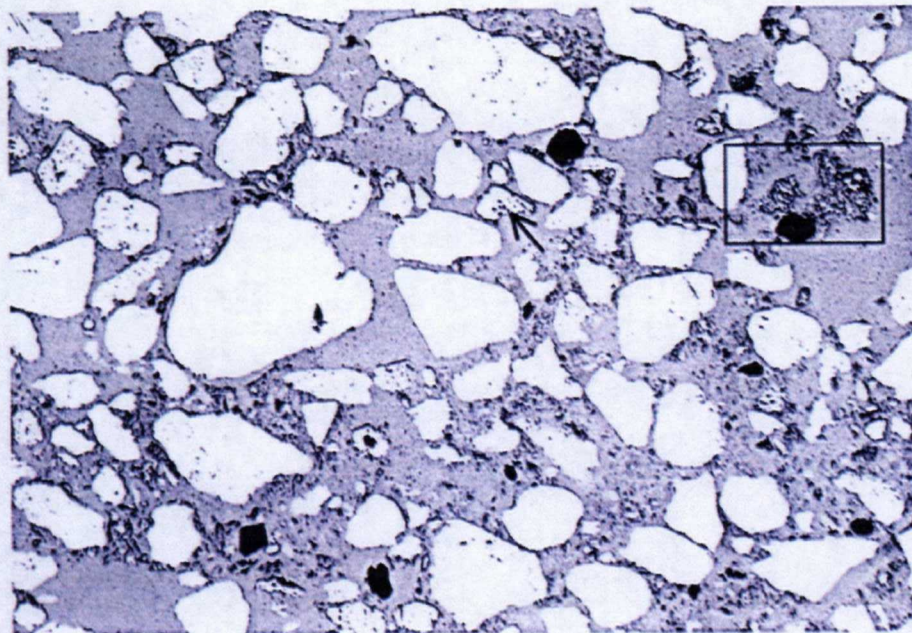
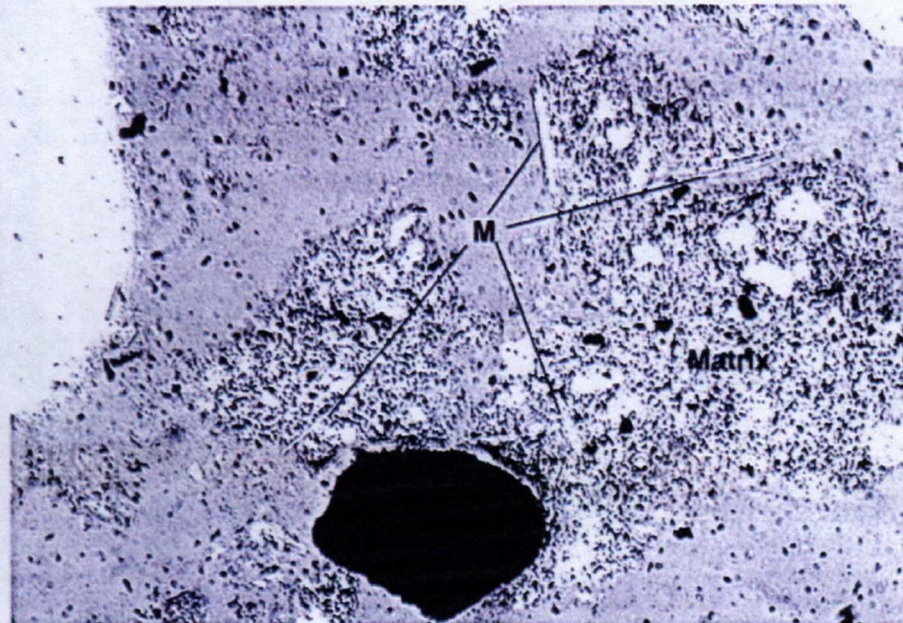


Plate 4B



GeoSyntec Consultants
Soil Samples
NL Industries Project
Sample: SV40
Depth: N.A.

Soil Type & Texture

Classification (Folk)	Silty sand
Grain Size (mm) (estimated)	Range = <0.01 - 2.05 Avg. = 0.36 (med. sand)
Grain Sorting	Poor
Grain Roundness	Rounded to angular
Compaction	Disaggregated
Structures	None evident

Composition (%)

Detrital Grains	Detrital Matrix
Mono. Qtz.	76.0
Poly. Qtz.	17.2
K-feldspar	1.2
Plagioclase	tr
Igneous R.F.	tr
Sedim. R.F.	0.4
Meta. R.F.	0.4
Chert	0.4
Biotite	tr
Muscovite	tr
Heavy Min.	0.4
Glaucanite	tr
Organics	tr
	Clay 2.4
	Authigenic Clay
	Kaolinite tr
	Chlorite tr
	Sericite tr
	Undiff. I/S 0.4
	Cements (non-clay)
	Quartz O.G. tr
	Feld. O.G.
	Dolomite
	Pyrite
	Iron Oxide tr
	TiO ₂ 1.2
	Organic

Photomicrograph Captions

Plate 4A: Patches of silty clay matrix (light brown) are irregularly distributed in the thin section. This view shows an area where the matrix is relatively common. A slightly dissolved (pitted) feldspar grain is noted by the arrow. Black sand grains are ilmenite/magnetite.

Plate 4B: The portion of Plate 4A within the black rectangle is displayed. The black grain is probably magnetite that has an oxidized rim. The oxidation has stained the adjacent clay matrix brown. Most of the view features a patch of matrix consisting of detrital silt and clay. A few muscovite (M) flakes are part of the silt fraction. The numerous black specks in the matrix are titanium oxide, with traces of iron oxide and possibly other materials. If any lead compounds are present, they would be most likely to occur as very tiny crystals within this matrix. XRD analysis indicates the clay fraction of the matrix is kaolinite and illite/mica.

APPENDIX C

Toxscan, Inc. Laboratory Report (October 1998)

RECEIVED OCT 13 1998

ToxScan, Inc. 42 Hangar Way • Watsonville, CA 95076-2404 • (408) 724-4522 • FAX (408) 724-3188

October 08, 1998

ToxScan Number: T-16324

GeoSyntec Consultants
10015 Old Columbia Road, Suite A-200
Columbia, MD 21046

Attn: Jeffrey Moore

Project Name: NL
Project Number: ME0015-13
Date Sampled: July 15, 1998 - September 23, 1998
Date Received: August 14, 1998 - September 23, 1998
Matrix: Soil Soil Extract

Please find the enclosed test results for the parameters requested for analyses. The samples were analyzed within holding time using the following methods:

Carbonate Cadmium by ICP/MS by EPA Method 200.8
Carbonate Lead by ICP/MS by EPA Method 200.8
Carbonate Lead by ICP/MS by EPA Method 200.8
Cation-Exchange Capacity by EPA Method 9081, conducted by Soil Control Lab
Extractable Cadmium by ICP/MS by EPA Method 200.8
Extractable Lead by ICP/MS by EPA Method 200.8
Extractable Lead by ICP/MS by EPA Method 200.8
Iron/Manganese Oxide/Hydroxide Cadmium by ICP/MS by EPA Method 200.8
Iron/Manganese Oxide/Hydroxide Lead by ICP/MS by EPA Method 200.8
Iron/Manganese Oxide/Hydroxide Lead by ICP/MS by EPA Method 200.8
Organic Cadmium by ICP/MS by EPA Method 200.8
Organic Lead by ICP/MS by EPA Method 200.8
Organic Lead by ICP/MS by EPA Method 200.8
Particle Size Distribution by Plumb
Percent Solids by EPA Method 160.3
pH by EPA Method 9045B
Residual Cadmium by ICP/MS by EPA Method 200.8
Residual Lead by ICP/MS by EPA Method 200.8
Residual Lead by ICP/MS by EPA Method 200.8
Total Metals by ICP/MS (Cd,Pb) by EPA Method 6020

This cover letter is an integral part of the report.

¹ Russell H. Plumb, Jr.; Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station; 1981.

October 08, 1998

ToxScan Number: T-16324

GeoSyntec Consultants
10015 Old Columbia Road, Suite A-200
Columbia, MD 21046

Attn: Jeffrey Moore

The samples were received intact and were handled with the proper chain-of-custody procedures. Appropriate QA/QC guidelines were employed during the analyses on a minimum of a 5% basis. QC results were within limits and are reported with or following the data for each analysis.

If you have any questions or require any additional information, please feel free to call.

Sincerely,



Philip D. Carpenter, Ph.D.
President

Enclosures

This cover letter is an integral part of the report.

¹ Russell H. Plumb, Jr.; Procedures for Handling and Chemical Analysis of Sediment and Water Samples, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station; 1981.

Client: GeoSyntec Consultants
Method: EPA Method(s) 200.8
Date Completed: 9/29/98
Matrix: Soil Extract
Units: mg/Kg

ToxScan Number: T-16324

Carbonate Metals

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910-12071598	16324-09	Cadmium	ND	0.1
		Lead	ND	0.1
SV2812-16071698	16324-10	Cadmium	ND	0.1
		Lead	0.17	0.1
SV071698-Dup	16324-11	Cadmium	ND	0.1
		Lead	0.14	0.1
SV26072098	16324-12	Cadmium	ND	0.1
		Lead	ND	0.1

SOIL CONTROL LAB

42 HANGAR WAY
WATSONVILLE
CALIFORNIA
95076
USA

In any reference, please
quote Certified Analysis
Number appearing hereon.

130152-4-3344

ToxScan Inc.
42 Hangar Way
Watsonville, CA 95076

A Division of Control Laboratories Inc.

05 OCT 98

CERTIFIED ANALYTICAL REPORT

MATERIAL: Soil samples received 27 August 1998
IDENTIFICATION: T-16324, Quanterra
ID NUMBERS: 1/4-4/4-130152

Sample ID:

Cation Exchange Capacity (C.E.C.)

SV2910-12071598
Dup

3.57 meq/100 g dw
1.70 meq/100 g dw

SV2812-16071698
Dup

1.13 meq/100 g dw
0.89 meq/100 g dw

SV071698-Dup
Dup

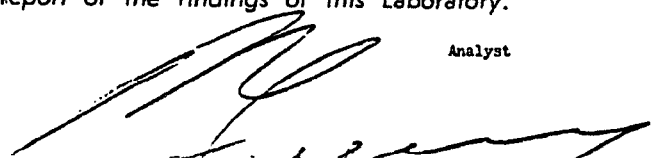
0.91 meq/100 g dw
0.91 meq/100 g dw

SV26072098
Dup

2.72 meq/100 g dw
1.83 meq/100 g dw

The undersigned certifies that the above is a true and
accurate report of the findings of this Laboratory.

Analyst



Client: GeoSyntec Consultants
Method: EPA Method(s) 200.8
Date Completed: 9/29/98
Matrix: Soil Extract
Units: mg/Kg

ToxScan Number: T-16324

Extractable Metals

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910-12071598	16324-09	Cadmium	ND	0.1
		Lead	ND	0.1
SV2812-16071698	16324-10	Cadmium	ND	0.1
		Lead	ND	0.1
SV071698-Dup	16324-11	Cadmium	ND	0.1
		Lead	ND	0.1
SV26072098	16324-12	Cadmium	ND	0.1
		Lead	ND	0.1

Client: GeoSyntec Consultants
Method: EPA Method(s) 200.8
Date Completed: 9/29/98
Matrix: Soil Extract
Units: mg/Kg

ToxScan Number: T-16324

Iron/Manganese

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910-12071598	16324-09	Cadmium	ND	0.1
		Iron	120	0.1
		Lead	0.36	0.1
		Manganese	33	0.1
SV2812-16071698	16324-10	Cadmium	ND	0.1
		Iron	26	0.1
		Lead	ND	0.1
		Manganese	ND	0.1
SV071698-Dup	16324-11	Cadmium	ND	0.1
		Iron	28	0.1
		Lead	ND	0.1
		Manganese	ND	0.1
SV26072098	16324-12	Cadmium	ND	0.1
		Iron	34	0.1
		Lead	0.14	0.1
		Manganese	ND	0.1

Client: GeoSyntec Consultants
Method: EPA Method(s) 200.8
Date Completed: 9/29/98
Matrix: Soil Extract
Units: mg/Kg

ToxScan Number: T-16324

Bound Organic Metals

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910-12071598	16324-09	Cadmium	ND	0.1
		Lead	ND	0.1
SV2812-16071698	16324-10	Cadmium	ND	0.1
		Lead	ND	0.1
SV071698-Dup	16324-11	Cadmium	ND	0.1
		Lead	ND	0.1
SV26072098	16324-12	Cadmium	ND	0.1
		Lead	ND	0.1

Client: GeoSyntec Consultants
Method: Plumb
Date Analyzed: August 3 - September 8, 1998
Matrix: Sediment

ToxScan Number: 16324

Client Sample ID: SV2910-12071598
Client Site ID:
ToxScan Lab ID: T-16324-05A

SIZE INTERVAL

Phi mm	INTERVAL WT (gm)	INTERVAL (%)	CUMULATIVE (%)
<-5 >32	0.00	0.0	0.0
-4 32-16	0.00	0.0	0.0
-3 16- 8	0.00	0.0	0.0
-2 8- 4	0.13	0.3	0.3
-1 4- 2	0.08	0.2	0.5
0 2- 1	0.16	0.4	0.9
1 1-0.5	2.26	5.3	6.2
2 0.5-0.25	12.57	29.4	35.6
3 0.25-0.125	16.85	39.5	75.1
4 0.125-0.062	8.01	18.8	93.9
5 0.062-0.031	1.23	2.9	96.7
6 0.031-0.016	0.41	1.0	97.7
7 0.016-0.008	0.29	0.7	98.4
8 0.008-0.004	0.16	0.4	98.7
9 0.004-0.002	0.08	0.2	98.9
>9 < 0.002	0.45	1.1	100
	total wt	coarse wt	fine wt
	42.7	40.1	2.6
	% sand	% silt	% clay
	93.9	4.9	1.3

GeoSyntec Consultants

ToxScan Number: 16324

Plumb

August 3 - September 8, 1998

Sediment

SV2812-16071698

T-16324-06A

<u>INTERVAL WT (gm)</u>	<u>INTERVAL (%)</u>	<u>CUMULATIVE (%)</u>
-------------------------	---------------------	-----------------------

0.00	0.0	0.0
0.00	0.0	0.0
0.00	0.0	0.0

1.33	3.2	3.2
0.85	2.1	5.3
1.43	3.5	8.7

6.81	16.5	25.3
19.83	48.1	73.3
8.76	21.2	94.5

0.86	2.1	96.6
0.25	0.6	97.2
0.19	0.5	97.7

0.21	0.5	98.2
0.12	0.3	98.5
0.09	0.2	98.7
0.54	1.3	100

total wt	coarse wt	fine wt
41.3	39.9	1.4

% sand	% silt	% clay
96.6	1.8	1.5

Client: GeoSyntec Consultants
Method: Plumb
Date Analyzed: August 3 - September 8, 1998
Matrix: Sediment

ToxScan Number: 16324

Client Sample ID: SV071698-Dup
Client Site ID:
ToxScan Lab ID: T-16324-07A

SIZE INTERVAL

Phi mm	INTERVAL WT (gm)	INTERVAL (%)	CUMULATIVE (%)
<-5 >32	0.00	0.0	0.0
-4 32-16	0.00	0.0	0.0
-3 16- 8	0.00	0.0	0.0
-2 8- 4	3.01	7.0	7.0
-1 4- 2	1.30	3.0	10.0
0 2- 1	2.20	5.1	15.2
1 1-0.5	7.09	16.5	31.7
2 0.5-0.25	19.35	45.1	76.8
3 0.25-0.125	7.91	18.4	95.2
4 0.125-0.062	0.76	1.8	97.0
5 0.062-0.031	0.20	0.5	97.5
6 0.031-0.016	0.21	0.5	98.0
7 0.016-0.008	0.16	0.4	98.3
8 0.008-0.004	0.13	0.3	98.6
9 0.004-0.002	0.06	0.1	98.8
>9 < 0.002	0.53	1.2	100
	total wt	coarse wt	fine wt
	42.9	41.6	1.3
	% sand	% silt	% clay
	97.0	1.6	1.4

Client: GeoSyntec Consultants
Method: Plumb
Date Analyzed: August 3 - September 8, 1998
Matrix: Sediment

ToxScan Number: 16324

Client Sample ID: SV26072098
Client Site ID:
ToxScan Lab ID: T-16324-08A

SIZE INTERVAL

Phi mm	INTERVAL WT (gm)	INTERVAL (%)	CUMULATIVE (%)
<-5 >32	0.00	0.0	0.0
-4 32-16	0.00	0.0	0.0
-3 16- 8	0.00	0.0	0.0
-2 8- 4	8.39	18.9	18.9
-1 4- 2	0.22	0.5	19.4
0 2- 1	0.31	0.7	20.1
1 1-0.5	2.23	5.0	25.1
2 0.5-0.25	10.95	24.6	49.7
3 0.25-0.125	13.97	31.4	81.1
4 0.125-0.062	5.39	12.1	93.2
5 0.062-0.031	0.76	1.7	94.9
6 0.031-0.016	0.46	1.0	95.9
7 0.016-0.008	0.33	0.8	96.7
8 0.008-0.004	0.31	0.7	97.4
9 0.004-0.002	0.14	0.3	97.7
>9 < 0.002	1.02	2.3	100
	total wt	coarse wt	fine wt
	44.5	41.5	3.0
	% sand	% silt	% clay
	93.2	4.2	2.6

Client: GeoSyntec Consultants
Method: EPA Method(s) 160.3
Date Completed: 8/26/98
Matrix: Soil
Units: Percent

ToxScan Number: T-16324

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Wet Wt. Sample Value</u>	<u>Wet Reporting Limit</u>
SV2910 - 12071598	16324-05	Percent Solids	83	0.10
SV2812 - 16071698	16324-06	Percent Solids	82	0.10
SV071698 - Dup	16324-07	Percent Solids	84	0.10
SV26072098	16324-08	Percent Solids	80	0.10

Client: GeoSyntec Consultants
Method: EPA Method(s) 9045B
Date Completed: 9/3/98
Matrix: Soil
Units: units

ToxScan Number: T-16324

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910 - 12071598	16324-05	pH	7.3	0.10
SV2812 - 16071698	16324-06	pH	6.6	0.10
SV071698 - Dup	16324-07	pH	6.0	0.10
SV26072098	16324-08	pH	6.2	0.10

Client: GeoSyntec Consultants
Method: EPA Method(s) 200.8
Date Completed: 9/29/98
Matrix: Soil Extract
Units: mg/Kg

ToxScan Number: T-16324

Residual Metals

<u>Client Sample ID</u>	<u>ToxScan Lab ID</u>	<u>Analyte</u>	<u>Sample Value</u>	<u>Reporting Limit</u>
SV2910-12071598	16324-09	Cadmium	ND	0.1
		Lead	2.2	0.1
SV2812-16071698	16324-10	Cadmium	ND	0.1
		Lead	0.96	0.1
SV071698-Dup	16324-11	Cadmium	ND	0.1
		Lead	0.87	0.1
SV26072098	16324-12	Cadmium	ND	0.1
		Lead	1.6	0.1

Client: GeoSyntec Consultants
Method: EPA Method(s) 6020
Date Completed: 9/10/98
Matrix: Soil
Units: mg/Kg

ToxScan Number: T-16324

Total Metals

<u>Client</u> <u>Sample ID</u>	<u>ToxScan</u> <u>Lab ID</u>	<u>Analyte</u>	<u>Wet Wt.</u> <u>Sample</u> <u>Value</u>	<u>Wet</u> <u>Reporting</u> <u>Limit</u>
SV2910 - 12071598	16324-05	Cadmium	ND	0.10
		Lead	2.8	0.10
SV2812 - 16071698	16324-06	Cadmium	ND	0.10
		Lead	1.9	0.10
SV071698 - Dup	16324-07	Cadmium	ND	0.10
		Lead	2.3	0.10
SV26072098	16324-08	Cadmium	ND	0.10
		Lead	4.1	0.10

EXPLANATION OF ACRONYMS FOR PROJECT # T-16324

The following is a glossary for acronyms that may be used in this report.

<u>Abbreviation</u>	<u>Definition</u>
LCS	Laboratory Control Sample
MS	Matrix Spike
MSD	Matrix Spike Duplicate
NA	Not Applicable
ND	None Detected
REP	Replicate
RPD	Relative Percent Difference
SRM	Standard Reference Material
TOC	Total Organic Carbon

QC FOR PROJECT # T-16324

LABORATORY METHOD BLANK SUMMARY

Applicable Matrix: Sediment

Total Metals

<u>Analyte</u>	<u>Amount</u>	<u>Reporting Limit mg/L</u>	<u>EPA Method Number</u>
Cadmium	ND	0.10	6020
Iron	ND	1.0	7380
Lead	ND	0.10	6020
Manganese	ND	0.10	6020

QC FOR PROJECT # T-16324

LABORATORY PRECISION SUMMARY:

Matrix: Soil

<u>Analyte</u>	<u>REP 1</u>	<u>REP 2</u>	<u>Units</u>	<u>RPD</u>
pH				
16324-08	6.20	6.19	units	0

QC FOR PROJECT # T-16324

Concentrations of the following are in mg/Kg

SRM SUMMARY:

Matrix: Sediment

Total Metals

<u>Analyte</u>	<u>Amount Found</u>	<u>Dilution</u>	<u>Corrected Value</u>	<u>SRM</u>	<u>Certified Value</u>	<u>% Recovery</u>
Cadmium	0.0136	20	0.272	MESS-2	0.240	114
Lead	0.955	20	19.1	MESS-2	21.9	87

QC FOR PROJECT # T-16324

Concentrations of the following are in ug/L

SRM SUMMARY:

Matrix: Water

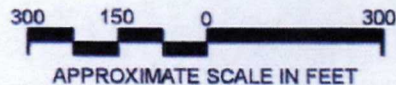
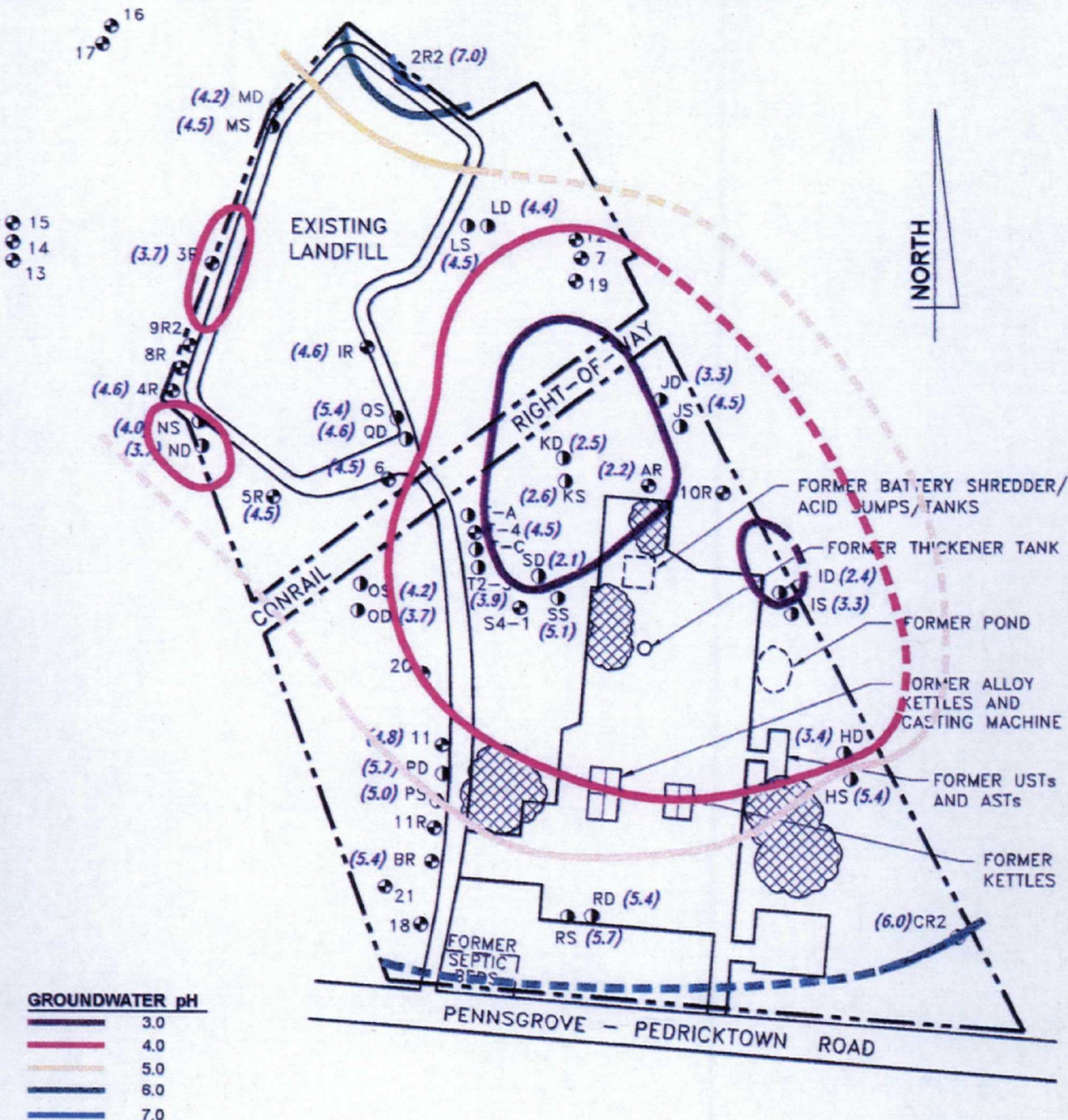
Total Metals

<u>Analyte</u>	<u>Amount Found</u>	<u>Dilution</u>	<u>Corrected Value</u>	<u>SRM</u>	<u>Certified Value</u>	<u>% Recovery</u>
Cadmium	24.0	5	120	ERA 9977	120	100
Iron	676	1	676	ERA 9977	667	101
Lead	128	5	641	ERA 9977	660	97
Manganese	18.6	5	93.0	ERA 9977	100	93

ERA 9977 = Environmental Resource Associates, WasteWatR Lot No. 9977

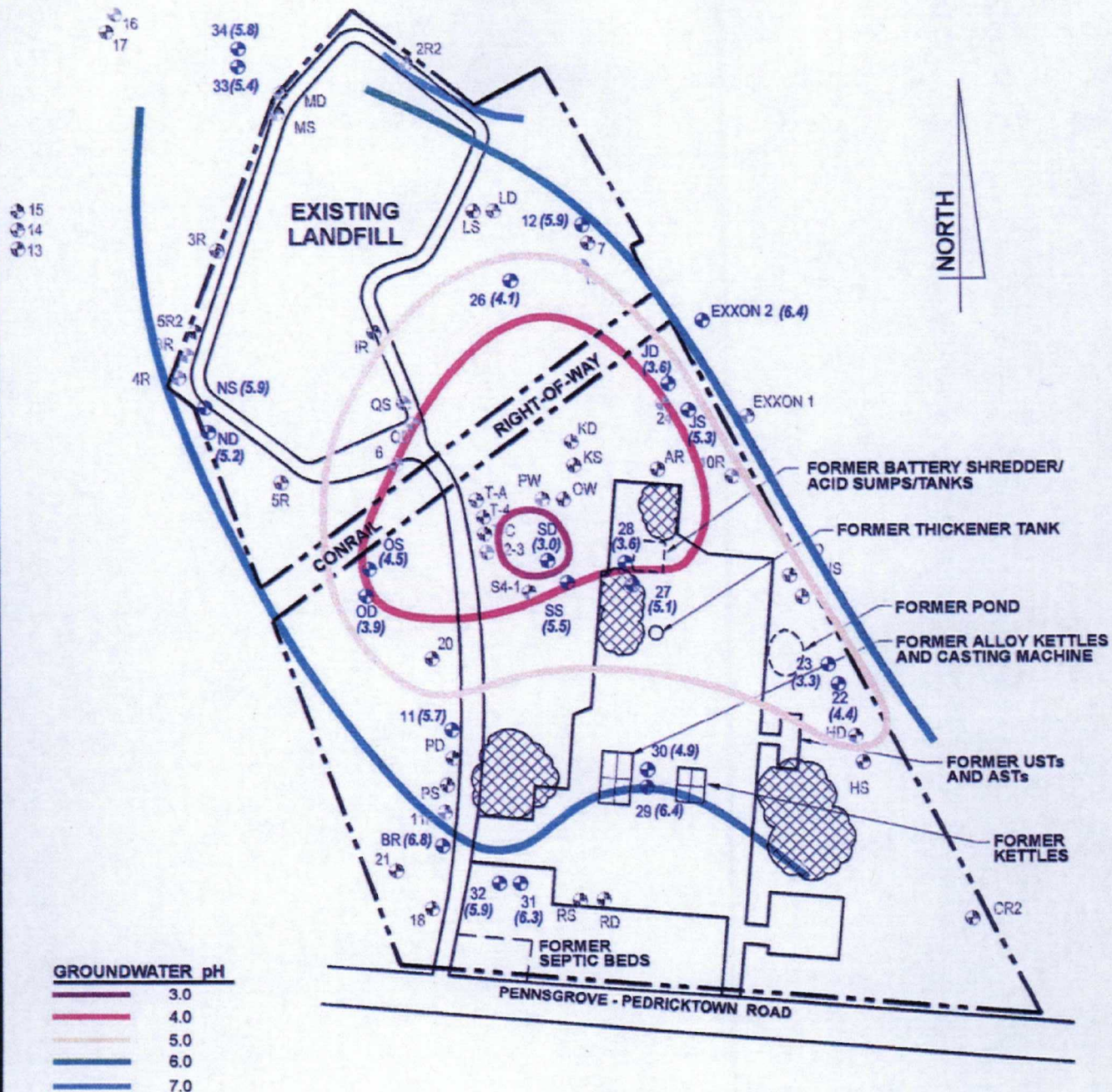
APPENDIX D

Current and Historical Groundwater pH Isopleths

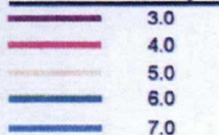


pH of Groundwater - 1983
NL Industries Site
Pedricktown, New Jersey

FIGURE NO.	7-5
PROJECT NO.	ME0015-15
DOCUMENT NO.	-
FILE NO.	phs2-ph83



GROUNDWATER pH



LEGEND

- WELL & DESIGNATION (NOT SAMPLED)
- BR WELL & DESIGNATION (SAMPLED)
- (18) LEAD CONCENTRATION (PPB)
- FORMER SLAG PILE LOCATION

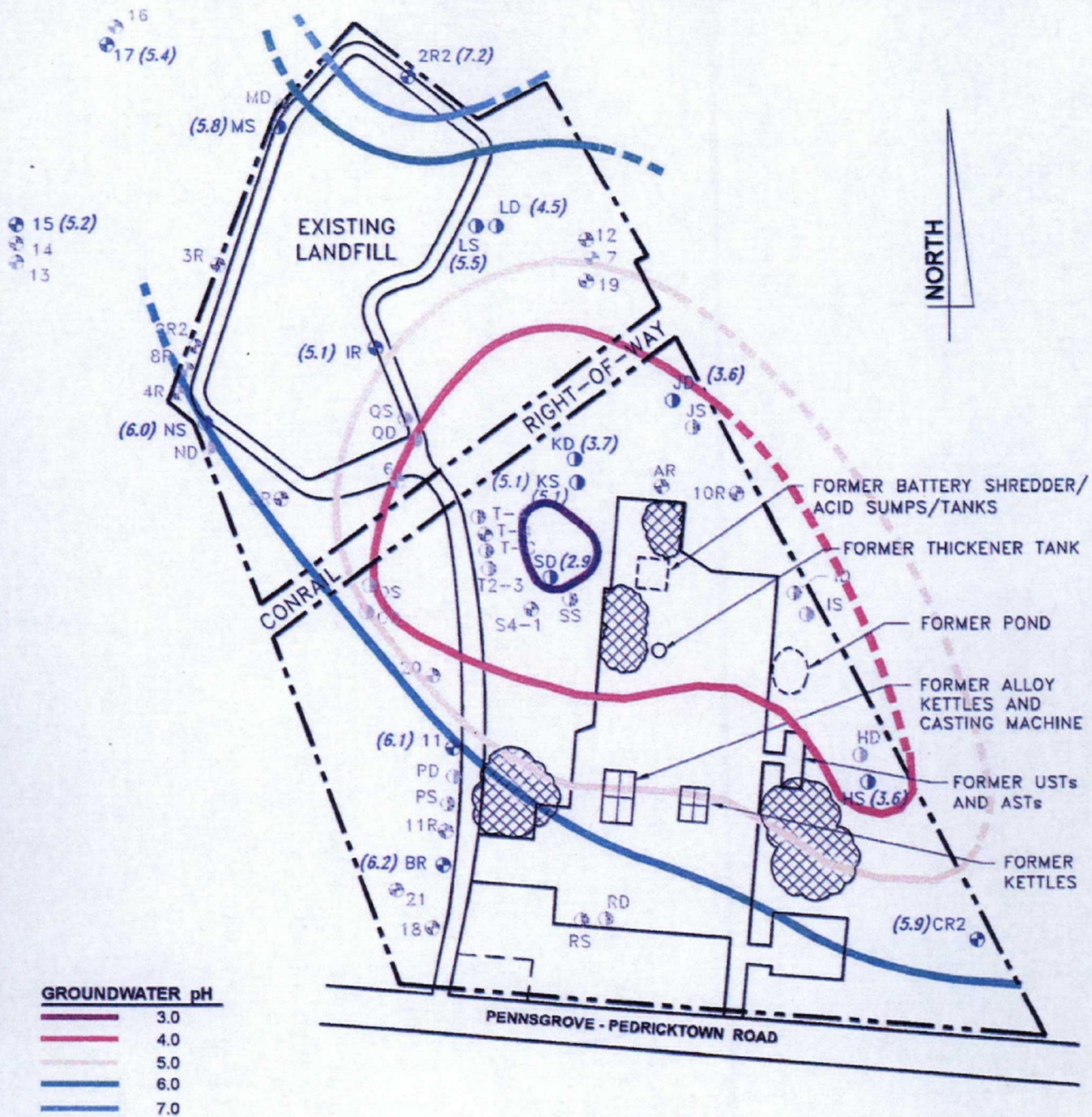
NOTE: GROUNDWATER pH CONTOURS SHOWN ARE A REPRESENTATIVE COMPOSITE OF DATA FROM SHALLOW AND DEEP WELLS IN THE UNCONFINED AQUIFER.

pH of Groundwater - 1998 NL Industries Site Pedricktown, New Jersey

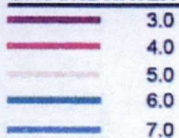
FIGURE NO.	7-3
PROJECT NO.	ME0015-15
DOCUMENT NO.	-
FILE NO.	phs2-ph98



GEOSYNTEC CONSULTANTS
COLUMBIA, MARYLAND



GROUNDWATER pH



LEGEND

- RD 2" WELL (NESTED PAIR) & DESIGNATION
- CR2 4" WELL & DESIGNATION
- (4.5) GROUNDWATER pH

○ FORMER SLAG PILE LOCATION

NOTE: GROUNDWATER pH CONTOURS SHOWN ARE A REPRESENTATIVE COMPOSITE OF DATA FROM SHALLOW AND DEEP WELLS IN THE UNCONFINED AQUIFER.

pH of Groundwater - 1997

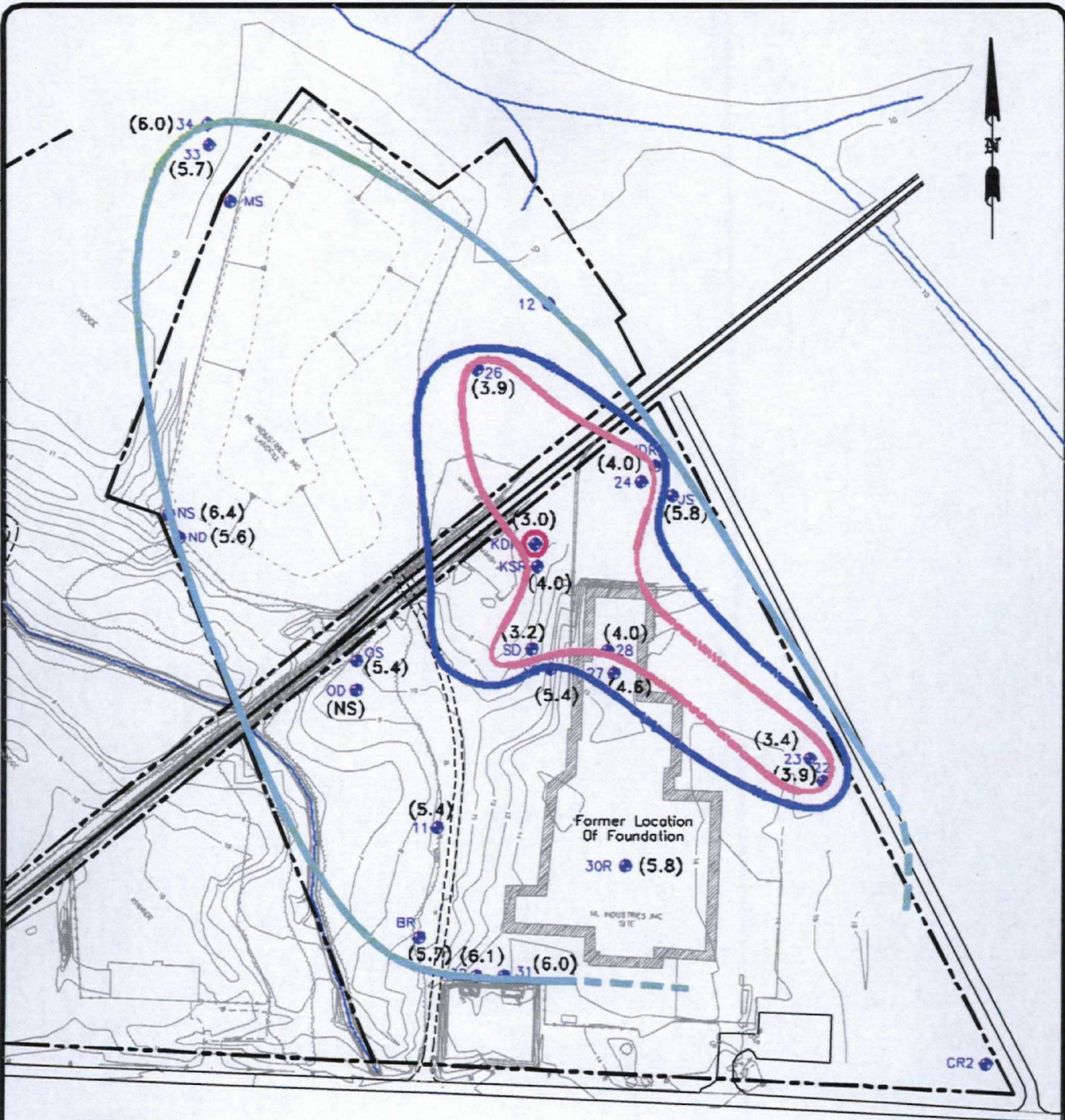
NL Industries Site
Pedricktown, New Jersey

FIGURE NO.	7-4
PROJECT NO.	ME0015-15
DOCUMENT NO.	-
FILE NO.	phs2-ph97



GeoSYNTEC CONSULTANTS

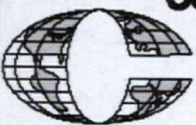
COLUMBIA, MARYLAND



LEGEND:

- CR2 ● MONITORING WELL
- pH 3
- pH 4
- pH 5
- pH 6

0 150 300
 SCALE IN FEET



CSI Environmental, LLC

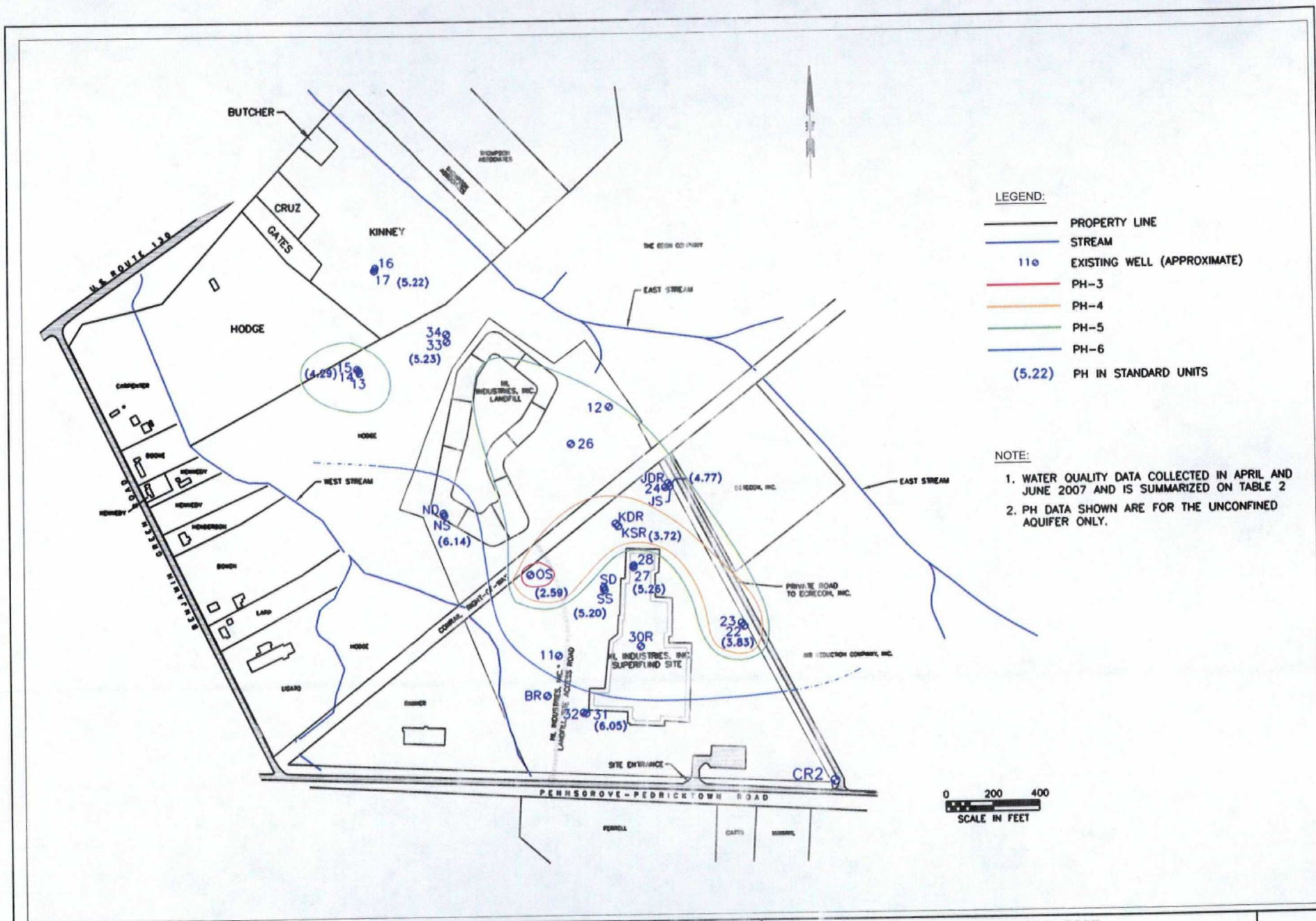
918 Chesapeake Ave.
 Annapolis, MD 21403
 410-268-2765

**Groundwater pH - 2004
 Shallow Zone**

NL Industries Superfund Site
 Pedricktown, New Jersey

FIGURE

3



CSI Environmental, LLC

918 Chesapeake Ave.
Annapolis, MD 21403
410-263-2765

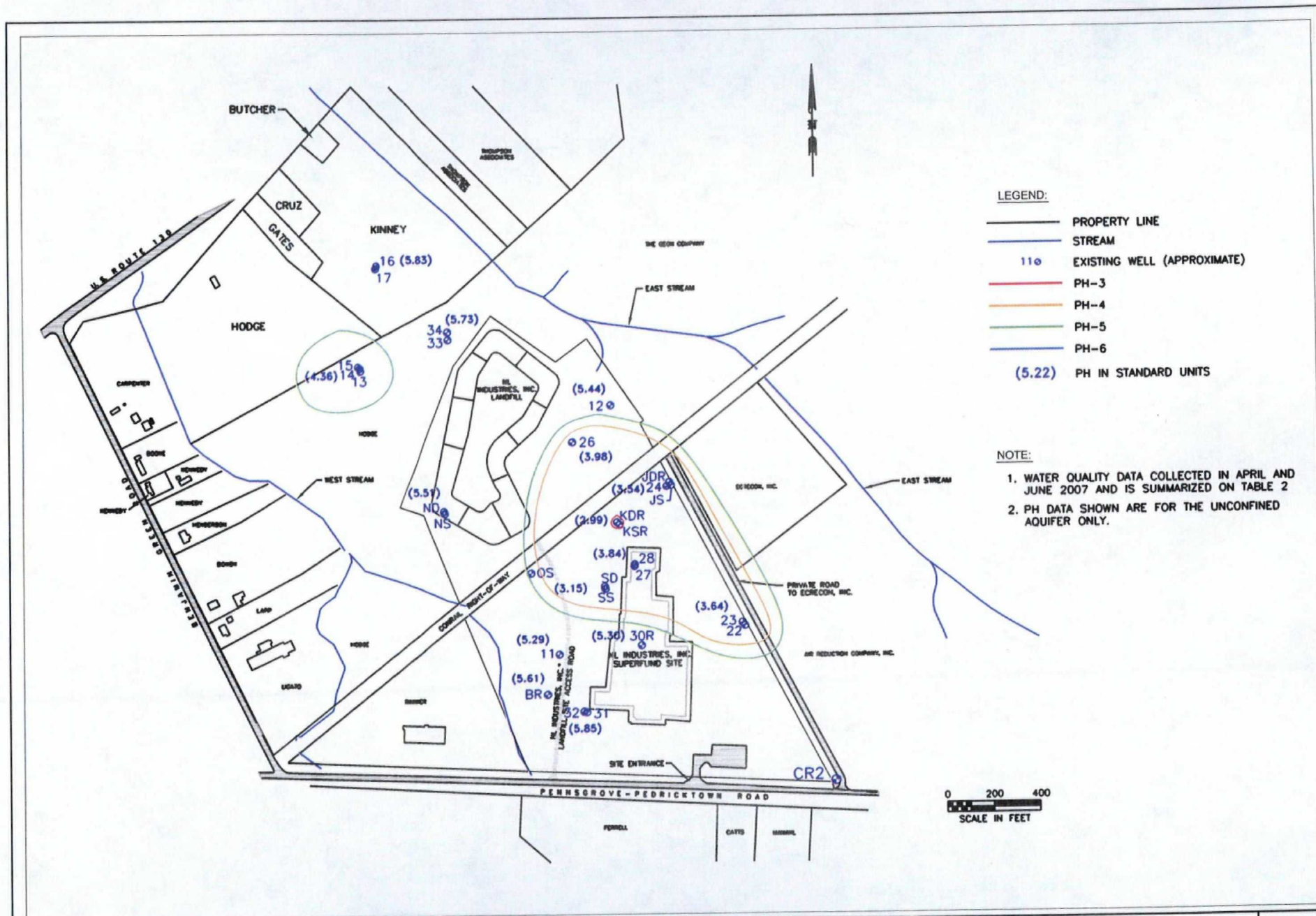


Groundwater PH - 2007
Shallow Zone

NL Industries Superfund Site
Pedricktown, New Jersey

FIGURE

3



CSI Environmental, LLC

918 Chesapeake Ave.
Annapolis, MD 21403
410-268-2765



Groundwater PH - 2007
Deep Zone

NL Industries Superfund Site
Pedricktown, New Jersey

FIGURE

4

APPENDIX E
Reagent Injection Bench Scale Treatability Study

WRT SERVICES, INC.

August 25, 2007

Mr. Jeff Moore
Senior Project Manager
Construction Services International, Inc.
918 Chesapeake Ave.
Annapolis, MD 21403

Re: NL Industries

Dear Jeff:

WRT Services conducted a laboratory bench study on behalf of CSI. The objective is to determine metal stabilization techniques for use at the NL Industries site, located in Pedricktown, NJ.

Background:

WRT Services was provided preliminary guidance for the bench tests as described in Section 3.3.3 Bench Scale Treatability Study, attached.

Water samples were obtained from four monitoring wells at the site. The samples were tested for:

- Lead
- Cadmium
- Iron
- Manganese
- Calcium
- COD
- TOC
- Sulfide
- Chloride
- Total Alkalinity
- Total Hardness

The groundwater is contaminated with lead and cadmium. These metals form insoluble complexes with several anions, including sulfide, carbonate, and phosphate. The ultimate treatment objective is to precipitate the target metals in situ and immobilize them. This would eliminate the need for a pump and treat remediation system, at least with respect to metals removal.

Theory

Soluble metals are usually present in solution as mono, divalent, or trivalent cations. Most toxic soluble metals are present as divalent cations. These cations may be reacted with divalent anions and if their solubility product (K_{sp}) is exceeded, the reaction products precipitate from solution. A compound's solubility is proportional to its solubility Product: The smaller the solubility product, the less soluble the species.

Metal hydroxides, $Me(OH)$, are generally two orders of magnitude more soluble than metal sulfides. Metal phosphates usually exhibit similar solubility products as metal sulfides. Note that rendering a metal insoluble does not necessarily immobilize the insoluble complex.

Metals may be immobilized by:

- Direct adsorption of a metal complex onto a substrate (i.e. the native rock)
- Incorporating the metal into a crystal lattice (intercalation), and subsequent incorporation within the native rock.
- Interlocking the metal into a non-homogenous material such as concrete or glass (vitrification)

Metal sulfides tend to adsorb onto a substrate. Phosphate immobilization is somewhat more complex. A host crystal, such as calcium carbonate is formed in solution with the target metal. If the charge and atomic radius of the target metal is the proper size, the target metal is incorporated into the host crystal and simultaneously rendered insoluble and inert.

Test Considerations:

The test protocol suggests evaluating metal precipitation with three compounds: Carbonate, sulfide, or phosphate. However, cadmium carbonate has significantly higher solubility than either cadmium sulfide or cadmium phosphate. In fact cadmium carbonate is more soluble than cadmium hydroxide. Metal hydroxide salts are generally not acceptable for in situ metal stabilization, so carbonate precipitation was eliminated from consideration.

There are other test design considerations with implications for a full scale remediation system.

Acidity/alkalinity:

From a practical viewpoint, high alkalinity and pH in excess of 7.0 are required for metal carbonate precipitation, adding to cost and application complexity. Metal phosphate precipitation also requires pH elevation, but alkalinity is not a consideration.

Safety and Toxicity:

If sodium sulfide is used for sulfide precipitation, then pH must be controlled to prevent evolution of explosive hydrogen gas. Sulfide precipitation conducted with organosulfur compounds is not subject to hydrogen gas evolution nor is pH control required.

Some organosulfur compounds, notably dithiocarbamates, are highly toxic to fresh water fish, so use of these reagents is avoided.

Cost:

Sodium sulfide is the least expensive sulfide precipitation reagent, but this was eliminated from consideration due to safety concerns.

Phosphate precipitation is not as simple as it may appear. The phosphate bearing reagent must supply the phosphate in the di-basic state. When metals form mono-basic salts with phosphate, the metal is adsorbed onto the face of the crystal, where it can be re-dissolved relatively easily. Thus, this will produce good laboratory results, but is not practical in real life applications. When metals are removed by crystalline formation with di-basic phosphate, the metals homogeneously precipitate within the host crystal, effectively immobilizing the metals.

Tri-sodium polyphosphate (TSPP) was selected for use, rather than phosphorous acid, even though it is somewhat more expensive than phosphoric acid, to insure that cadmium and lead were removed as dibasic

phosphate salts. Tri-sodium polyphosphate also eliminates the safety concerns of handling strong mineral acid in field application.

Solubility Products:

CdCO ₃	1×10^{-12}
Cd(OH) ₂	7.2×10^{-15}
Cd ₃ (PO ₄) ₂	2.53×10^{-33}
CdS	3.6×10^{-29}
Pb(OH) ₂	1.0×10^{-16}
PbS	3.4×10^{-28}
Pb(PO ₄)	

Baseline Groundwater Chemistry

		TDS ppm	pH	Cadmium ppb	Lead ppb	Iron ppm	Manganese ppm
Sample Location							
Well	SD	28,500	3.08	149	31	294	8.0
Well	OS	5,400	3.09	4	388	8	0.2
Well	SS	767	5.25	11	83	24	0.5
Well	KDR	5,740	2.83	141	ND	78	4.0

Test Procedure:

Reagent Selection:

1. Tri-sodium phosphate (TSPP) was chosen to generate calcium phosphate in the presence of lead and cadmium.
2. Calcium chloride solution was used in conjunction with TSP to supply the calcium ion required to form calcium phosphate.
3. A 5% solution of sodium hydroxide was used for pH adjustment in all experiments requiring pH increase.
4. A liquid organosulfur compound, Trimercaptotriazine (TMT-15, manufactured by Degussa), was chosen to precipitate lead and cadmium. TMT was selected as the reagent because it has essentially no aquatic toxicity at use concentration.

Test matrix:

Three sets of tests were conducted on each sample point. The objective was to simultaneously precipitate cadmium and lead.

Test A:

No pH adjustment.

Determine the dose of Trimercaptotriazine required for each sample.

The dose is determined by:

- Calculating the stoichiometric demand to precipitate all the known metals (iron, manganese, cadmium, and lead).
- Add TMT-15 at 1.5 times the stoichiometric requirement to compensate for any reagent demand from unknown metals.

Mix for 30 seconds at 120 rpm using a Phipps and Bird mechanical stirrer (gang stirrer).

Allow to stand and settle for five (5) minutes.

Filter through # 40 Whatman paper and retain filtrate for metals analysis

Acidify and refrigerate retained samples

Ship to Lancaster Laboratories for cadmium and lead determination.

Test B:

Qualifiers:

1. Sulfide precipitation is usually conducted at mildly alkaline pH.
Each groundwater was acidic: Several are strongly acidic.
Determine if pH adjustment is required to augment sulfide precipitation
2. Iron and manganese create demand for sulfide reagent.
Iron and manganese may be inexpensively precipitated by pH adjustment in excess of 8.0, using (inexpensive) sodium hydroxide.
If iron is removed as iron hydroxide, the sulfide reagent can be preserved to precipitate the more soluble metals, cadmium and lead, at relatively lower cost.

Adjust pH to 8.5.

Add 30 ppm, active ingredient basis, of Trimercaptotriazine

Mix for 30 seconds at 120 rpm using a Phipps and Bird mechanical stirrer (gang stirrer).

Allow to stand and settle for five (5) minutes.

Filter through # 40 Whatman paper and retain filtrate for metals analysis

Acidify and refrigerate retained samples

Ship to Lancaster Laboratories for cadmium and lead determination.

Test C:

Add 100 ppm of TSPP solution

Mix 30 seconds at 120 rpm

Add 200 ppm of Calcium Chloride solution

Mix for 30 seconds at 120 rpm

Adjust pH to 8.5 with sodium hydroxide solution

Mix for 30 seconds at 120 rpm.

Allow to stand and precipitate for five (5) minutes.

Filter through # 40 Whatman paper and retain filtrate for metals analysis

Acidify and refrigerate retained samples

Ship to Lancaster Laboratories for cadmium and lead determination.

Notes:

- Each test was conducted with 500 ml of sample, unless noted otherwise.
- Initially a 2:1 ratio of calcium to phosphate was selected to insure that the reaction was driven to completion. The desired crystalline end product is: $\text{Ca}_5(\text{PO}_4)_3(\text{OH})_4$
- Calcium chloride dose modified to compensate for impact of iron phosphate formation.
- Each test was post treated with 10 ppm of anionic polyacrylamide copolymer to induce particle agglomeration and enhance filtration.

Sample OS:

Test A:

14.5 ppm of known metals present in sample

Dose with 0.1 ml of TMT-15 = 30 ppm active Trimercaptotriazine

Initial pH = 3.09

pH after TMT addition = 3.59

Test B: Adjust pH with 5% solution of sodium hydroxide

Add 1 cc of 5% sodium hydroxide: pH increases to 7.27

Add an additional 0.38 cc: pH = 8.52

Visible Pinfloc: Probably iron hydroxide

Add 0.1 cc of TMT-15 (30 ppm active ingredient): pH = 8.62

Stronger, more voluminous floc generated compared to Test A.

Test C: Add 2 cc of 5 % TSPP and mix: pH = 4.41

Add 1 cc of 5% CaCl_2 and mix: pH = 4.46

Increase pH to 8.5 with 5 % sodium hydroxide

Add 0.5 cc: pH = 8.30

Increase dose to 0.58 cc: pH = 8.56

Pinfloc visible after pH adjustment.

Sample SS:

Test A:

TMT demand calculated at 458 ppm active ingredient

Note: Test volume = 700 ml.

Dose with 2.2 ml of TMT-15 = 471 ppm active Trimercaptotriazine
Mix

Initial pH = 5.25

pH after first TMT addition = 9.25

Creates suspended colloidal solids: Difficult to precipitate

Increase TMT dose by 1.0cc: Total concentration now = 685 ppm a.i.

Iron in filtrate = 6.70 ppm

Test B: Adjust pH with 5% solution of sodium hydroxide

Add 0.5 cc of 5% sodium hydroxide: pH = 5.45

Increase to 1 cc of 5% sodium hydroxide: pH increases to 9.25

Sample is not buffered.

Add 3.2 cc of TMT-15:

Colloidal, turbid solution: No pinfloc

Iron in filtrate = 1.80 ppm

Test C: Modify procedure: Add 1 pt of TSPP per part of iron in sample
Add 100 ppm of TSP to remove cadmium and lead.

Add 1.3 cc of 5 % TSPP (100 ppm) for cadmium and lead

Add 0.5 cc TSPP (30 ppm) for iron

Add 2.6 cc of 5% CaCl_2 and mix: pH = 6.35

Add 0.65 cc of 5 % sodium hydroxide: pH = 9.26

Iron in filtrate = 0.33 ppm

Precipitates easily after anionic polymer addition:

Generates crystal clear water

Sample SD:

Test A:

TMT demand calculated at 1218 ppm active ingredient

Note: Test volume = 700 ml.

Dose with 22 ml of TMT-15 = 4714 ppm active Trimercaptotriazine
Mix

Massive, voluminous black floc

TMT: Metal ratio = 4:1: Too much TMT.

Initial pH = 3.04

pH after first TMT addition = 7.05

Note: Filtrate discolors: Reacts with nitric acid when sample is fixed: Indicates
excess TMT.

Iron in sample reported as 296 ppm

Iron in filtrate = 135 ppm

Test B: Adjust pH with 5% solution of sodium hydroxide

Add 19.2 cc of 5% sodium hydroxide: pH = 8.48

Add 11 cc of TMT-15:

Iron in filtrate = 0.17 ppm

Test C: Modify procedure: Add 1 pt of TSPP per part of iron in sample
Add 100 ppm of TSP to remove cadmium and lead.

Add 8.4 cc of 5 % TSP pH = 3.33

Add 16.8 cc of 5% CaCl_2 and mix: pH = 3.22

Add 18.7 cc of 5 % sodium hydroxide: pH = 8.54

Iron in filtrate = 3.20 ppm

Sample KDR:

Sample pH = 2.88

Sample iron = 52 ppm (GFR test) Reported as 78 ppm.

Volume for all three tests = 700 ml.

Test A:

TMT demand calculated at 770 ppm active ingredient

Dose with 4.5 ml of TMT-15 = 964 ppm active Trimercaptotriazine Mix

Large floc with clear water

pH after TMT addition = 4.70

Iron in filtrate = 13.5 ppm

Test B:

Add 3.25 cc of 5% sodium hydroxide: pH = 8.62

Add 3.8 cc of TMT-15: pH = 9.39

Iron in filtrate = 0.26 ppm

Test C:

Add 2.2 cc of 5 % TSPP (152 ppm) pH = 2.85

Add 2.9 cc of 5% CaCl₂ (200 ppm): pH = 2.84

Add 4.0 cc of 5 % sodium hydroxide: pH = 8.75

Iron in filtrate = 0.18 ppm

Results:

Sample	Test	Cadmium ppm	Lead ppm
SS	Control	0.0091	0.0710
	Test A	0.0053	0.0263
	Test B	<0.0050	<0.0150
	Test C	<0.0050	<0.0150
KDR	Control	0.0793	<0.0150

	Test A	<0.0050	<0.0150
	Test B	<0.0050	<0.0150
	Test C	<0.0050	<0.0150
OS	Control	no test	no test
	Baseline	0.0040	0.3800
	Test A	0.0070	0.3200
	Test B	<0.0050	<0.0150
	Test C	<0.0050	<0.0150
SD	Control	0.1970	< 0.0750
	Test A	<0.0250	< 0.0750
	Test B	<0.0250	< 0.0750
	Test C	<0.0250	< 0.0750

Relative application costs:

Cost comparisons were made between:

- Treatment A: Organosulfur
- Treatment B: Organosulfur with pH adjustment
- Treatment C: Trisodium polyphosphate

The results for Groundwater source SD and SS were evaluated.

- All three treatments worked effectively on Groundwater Source SD
- Trisodium Polyphosphate was more effective for removing lead and cadmium from Groundwater Source SS

Treatment cost per 1000 gal. of groundwater

Treatment	SD	SS
A: OrganoSulfur	\$ 488	\$ 11
B: Organosulfur with pH adjustment	\$ 252	\$ 72
C. Sodium Tripolyphosphate	\$ 9	\$ 1

Cost Basis:

Sodium tripolyphosphate supplied in dry bulk shipments at \$ 42.00/CWT	(\$ 0.42/lb.)
Calcium chloride supplied in dry, bulk shipments at \$ 182/ton:	(\$ 0.09/lb.)
Sodium hydroxide supplied in 330 gal. tote bin containers, at 25% solution strength at \$ 14.25/CWT:	(\$ 0.1425/lb.)
Degussa TMT-15 supplied in semi-bulk, 275 gal. tote bin containers at:	(\$ 1.87/lb.)

Conclusion:

As expected both phosphate and sulfide precipitation remove cadmium and lead from solution.

The four test water sources each contain relatively low concentrations of lead and cadmium, which makes trend analysis somewhat difficult. Results with phosphate removal are more concise than with sulfide removal.

Cost wise, phosphate precipitation is clearly more effective than organosulfur. There are less expensive chemical sources of sulfide, however these have a host of application associated difficulties, as detailed within this report.

The study only addresses the issue of effective precipitation. One assumes that the lead and cadmium are intercalated within the calcium phosphate crystalline lattice, and thus, effectively demobilized. Further study is required to verify this assumption.

Thank you for the opportunity to be of service to CSI, Inc. Please contact me with questions regarding this study.

Regards,

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APPENDIX F
Permeable Reactive Barrier Example Studies

- *In-vitro extraction test*, a simplified PBET using an aqueous solution to simulate gastrointestinal fluid into which contaminated soil is introduced.

ERTC worked with field staff to demonstrate use of these TPM's for evaluating organic-amendment technology at mining sites in Leadville, CO, Jasper, MO, Kellogg, ID, Picher, OK, and Prescott, AZ. Although regulatory concurrence on technology effectiveness varies, consistent application of TPMs allows for efficiency comparisons across similar technologies involving similar costs. EPA is working with other organizations such as the Interstate Technology and Regulatory Council to establish cost-effective and consistent protocols for using these TPMs.

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PRB Containing Processed Fish Bones Sequesters Metals from Ground Water

Over the past decade, the U.S. Department of Defense, U.S. EPA, and other government or academic agencies sponsored demonstrations employing biogenic apatite as a reactive agent for remediation of soil and ground water. Early applications involved circulating pumped ground water into treatment tanks containing processed fish bones (known as Apatite II™) or the direct mixing of apatite into soil (see the March 2002 issue of *Tech Trends*, online at <http://www.cluin.org/products/newsletters/ttrend/archive.cfm>). More recently, apatite served as the reactive medium in a PRB demonstration at the Success Mine and Mill site in northern Idaho. Evaluation of the system's performance over four years indicates that the PRB reduced concentrations of target metals in ground water 99%, significantly above the anticipated 75% reduction, but experienced difficulty maintaining a constant flow of water.

The PRB was installed in 2001 to address leaching of metals from approximately 500,000 tons of mine tailings at a former disposal area adjacent to a tributary of the Coeur d'Alene River. Below the tailings, an alluvial layer extends to bedrock at 16-20 feet bgs. Investigations indicated that soil contained lead, zinc, and cadmium in concentrations ranging from 1,000 to 4,000 mg/kg. Ground-water and surface seeps also contained elevated concentrations of the metal leachates, reaching 1.25 mg/L for cadmium, 1.44 mg/L for lead, and 177.0 mg/L for zinc.

Biogenic apatite was selected as the reactive medium due to its ability to stabilize metals in water through precipitation, co-precipitation, sorption, or biological stimulation. In addition, the organic carbon in apatite could serve as both an electron donor and carbon source for sulfate-reducing bacteria that accelerate precipitation of metal (particularly zinc) sulfides directly onto the reactive medium surface. Based on the results of bench-scale tests performed by the Idaho Department of Environmental Quality (IDEQ), fish-bone apatite was selected for the PRB rather than alternate forms such as synthetic hydroxyapatite, mineral

apatite from phosphate rock, or cow bones.

Construction of the PRB involved excavation of a 15-ft-wide trench extending 14 feet bgs and 50-ft-long and between the tailings pile and creek. The trench was lined with type-V Portland cement in a baffled pattern to create a two-cell vault that would uniformly receive seep and alluvial ground-water flow. Each cell contains five 6-ft-wide, 9-ft-long chambers separated by plywood baffles that bring ARD into optimal contact with the reactive medium. Both cells were filled with 100% Apatite II.

The vault was plumbed and valved to allow sampling and potential replacement of the reactive media. A 1,200-ft grouted containment wall and hydraulic drain were installed upgradient of the PRB to divert water to the treatment vault while reducing migration of any contaminants bypassing the system. Captured ARD flows from the drain through underground piping and into the vault, where the water is split and piped into each of the two cells for parallel treatment. Upon exiting the vault, treated water discharges to a rock apron that routes it into the nearby creek. Water passes through the vault at a rate of approximately 5 gpm, resulting in a total residence time of approximately 24 hours.

After a year of operation, one of the cells exhibited plugging. A 1:1 mixture of pea gravel and apatite was mixed into the cell to increase porosity and the rate of treatment flow. Data collected over four years of monitoring indicate that water exiting the PRB contains lead and cadmium in average concentrations below the detection limits of 0.005 mg/L and 0.002 mg/L, respectively. Zinc concentrations also decrease as a result of treatment, to below the average background level of 0.100 mg/L. Concentrations of these metals in the effluent consistently meet the State of Idaho criteria for drinking water. In addition, pH of the water increases from 4.5 before treatment to 6.5-7.0 upon exiting the PRB. Slightly elevated concentrations (approximately 10 ppm) of chemical byproducts such as ammonia and phosphate exist in water exiting the vault but decrease after passing through the rock apron.

Sample analysis also shows that water entering the vault contains an average sulfate concentration of 250 mg/L, while sulfate in water exiting the system ranges from 35 to 150 mg/L. X-ray diffraction analysis performed by Idaho National Laboratory (INL) confirmed high concentrations of sulfate in precipitates formed in the media. Detailed analyses of microbial communities within the PRB suggest that sulfate-reducing *Enterococci* bacteria are the primary drivers of sulfate reduction in the ARD. Analysis of the treated water indicates that these microbial populations do not exist in the system effluent. Changes in key ground-water parameters indicate that a corresponding increase in metal precipitation is caused by the sulfate-reducing bacteria within the PRB (Figure 3).

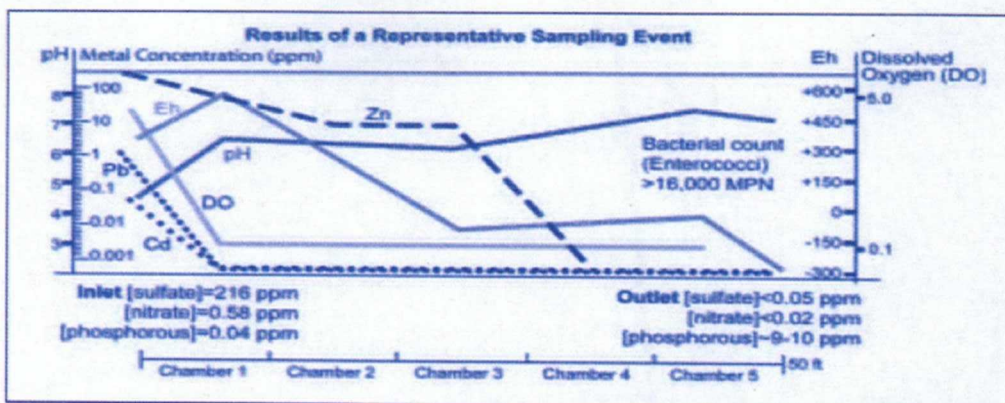


Figure 3. Changes in key ground-water parameters within the Apatite II PRB indicate that pH of the ARD is buffered during treatment and that metals are sequestered from ARD primarily within the first two treatment chambers.

Although influent initially entered the PRB at a rate of approximately 30 gpm, it quickly decreased to and remained at 5 gpm due to intake buildup of suspended alluvial silica and breakdown of the apatite. Subsequent system optimization conducted by researchers from INL and IDEQ involved replumbing of the intakes, which had little effect on the rate of treatment flow. In addition, INL injected air into both treatment cells during a single event last spring in order to aerate the apatite medium and to decrease overflow at both of the cell inlets. Air sparging resulted in a 7- to 15-fold temporary increase in treatment flow and cessation of the overflow. Overall results indicate that mixing of apatite with pea gravel did not improve the rate of treatment flow or decrease performance of the system.

A total of approximately 150 pounds of lead, 100 pounds of cadmium, and 10,000 pounds of zinc were sequestered in the vault during the demonstration, over 80% of which collected in the first two treatment chambers of both cells. As of mid 2005, field investigations suggested that about 40% of the barrier was spent. The reactive media consequently were removed from the apatite/gravel cell and disposed onsite as non-hazardous waste later in the year. The cell was re-filled with limestone in the first chamber and a mixture of apatite and plastic packing rings (to provide additional aeration) in the remaining four chambers.

Due to its extremely high concentrations relative to lead or cadmium, zinc is expected to serve as the indicator of PRB break-through. Longevity of the PRB will depend upon the ability to reduce system plugging and maintain an adequate rate of treatment flow. Construction of the PRB cost more than \$500,000, including \$35,000 for 100 tons of Apatite II.

Similar performance results were demonstrated for an apatite PRB at the Nevada Stewart Mine Site near Wallace, ID, where routine air injections are performed to reduce system plugging. Animal toxicity studies conducted by the IDEQ at that site (using the invertebrate *Ceriodaphnia dubia* and the fathead minnow

Pimephales promelas.) demonstrated complete toxicity removal for both species from contaminated water that had passed through the PRB. Additional microbiological studies recently conducted at New Mexico State University (NMSU) suggest that apatite can induce biodegradation of contaminants such as perchlorate, TNT, and RDX.

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MWTP Demonstrates Integrated Passive Biological System for Treating Acid Rock Drainage

The U.S. EPA and U.S. DOE recently completed a four-year, pilot-scale demonstration of a passive biological system for treating ARD at the Surething Mine near Elliston, MT. Mining of gold, zinc, and lead at this mine from the late 1800's until the mid 1950's exposed sulfide mineralization to the environment, which led to ARD discharge from the mine adit. In addition to being highly acidic, the ARD contained elevated concentrations of iron, aluminum, copper, zinc, lead, arsenic, cadmium, and manganese. This demonstration was one of several sponsored by the Mine Waste Technology Program to identify effective source-control technologies for retarding or preventing acid generation at mining sites.

The technology's multi-stage process at the Surething Mine involved sequential passage of ARD from the mine adit through three adjacent anaerobic reactors and an aerobic reactor. Anaerobic treatment relied on sulfate-reducing bacteria that reduced dissolved sulfate to hydrogen sulfide, which reacted with dissolved metals to form insoluble metal sulfides. This bacterial metabolism also produced bicarbonates that increased pH of the ARD and limited dissolution of metal. Seven of the eight target metals were addressed through the anaerobic process.

The treatment system was constructed in the summer of 2001. It was designed to treat a maximum ARD flow rate of 2 gpm, although rates varied due to seasonal influences and reached 10 gpm during spring runoff. The first anaerobic reactor through which ARD passively flowed was constructed of a mixture of cow manure and walnut shells. Cow manure provided a source of easily degradable organic carbon and large populations of sulfate-reducing bacteria. The walnut shells provided a longer-term source of organic carbon and the structural strength needed to maintain permeability of the mixture. Bench-scale tests indicated that this initial reactor would successfully establish the sulfate-reducing conditions needed for the overall system, but also that it would be the first to fail due to bacterial incompatibility with the low pH of feed water. Sulfate-reducing capabilities also were challenged by the presence of iron ion in the ARD, 95% of which existed in the ferric state.

Drainage water then flowed passively through the second anaerobic reactor, which was constructed of limestone cobbles that added alkalinity to the water.

TREATMENT OF ACID MINE DRAINAGE USING FISHBONE APATITE IITM₁

Neal A. Yancey₂ and Debby Bruhn₃

ABSTRACT. In 2000, a reactive barrier was installed on the East Fork of Ninemile Creek near Wallace, Idaho to treat acid mine discharge. The barrier was filled with fishbone derived Apatite IITM₄ to remove the contaminants of concern (Zn, Pb, and Cd) and raise the pH of the acidic mine discharge. Metal removal has been achieved by a combination of chemical, biological, and physical precipitation. Flow for the water ranges from 5 to 35 gallons per minute. The water is successfully being treated, but the system experienced varying degrees of plugging. In 2002, gravel was mixed with the Apatite IITM to help control plugging. In 2003 the Idaho National Laboratory was ask to provide technical support to the Coeur d'Alene Basin Commission to help identify a remedy to the plugging issue. Air sparging was employed to treat the plugging issues. Plastic packing rings were added in the fall of 2005, which have increased the void space in the media and increased flows during the 10 months of operation since the improvements were made.

Additional Key Words: reactive barrier, heavy metals, mining.

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⁴ **Product Disclaimer:**

References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government, any agency thereof, or any company affiliated with the Idaho National Laboratory.

BACKGROUND

The Coeur d'Alene Basin of Northern Idaho is known as Silver Valley because of the huge volume of silver mined in the area in the early 1900s. As a result, thousands of acres of land and miles of streams have been contaminated with metals from the mining and milling activity (Gillerman 2002). Stabilizing stream banks and tailings piles that are sources of sediment and particulate metals in the creeks is one cleanup activity that is being implemented in the Coeur d'Alene Basin. In some locations, tailings have been piled on the canyon floors and cover the original creek channels. Water now flows through the tailings, where it picks up dissolved and suspended metals (Figure 1). The Success Mine site was identified as the largest remaining source of metals loading in the Ninemile Creek drainage (EPA 2002). Zinc, cadmium and lead concentrations are significantly higher in this area than background areas. During high flows in the spring, sediments that were trapped during low flow periods are resuspended and carried downstream. The pH of the water is also lower in this area due to the presence of pyrite formations (Golder Associates Inc., 2002).



Figure 1.0 Ground and Surface Water Passing through Mine Tailings

Groundwater flows from the adjacent hillsides and comes up in various locations in the canyon floor. Portions of this water comes up through the tailings pile and flows down gradient until it enters the creek, again carrying with it increased levels of dissolved and suspended metals with a lowered pH level.

INTRODUCTION

In 2000, a 45 foot long 12 foot deep reactive barrier was constructed to treat acid mine drainage resulting from surface and groundwater passing through mine and mill tailings at the Success Mine on the East fork of Ninemile Creek near Wallace, Idaho. The reactive barrier was constructed having two separate sides, each 6 foot wide, 12 feet deep, and 45 feet long (See Figure 2). On each side of the reactive barrier, water flows over and under alternating baffles to

create as much contact between the media and contaminated water as possible. Each side of the reactive barrier has 5 cells separated by these alternating baffles (Figure 2).

The reactive barrier was filled with fishbone Apatite IITM as a media to remove the metal contaminants and to raise the pH of the water. Apatite IITM, derived from fish bones, stabilized a wide range of metals, including Zn, Pb, and Cd (Write et al., 1995). Depending on the metal concentration and water chemistry, the Apatite IITM works by four possible processes: heterogeneous nucleation, pH buffering, chemisorption, and biological stimulation (Wright and Conca 2005). From the start, the reactive barrier successfully removed metals from the contaminated discharge, as well as early on, the system began experiencing plugging problems.



Figure 2.0. Construction of the Reactive Barriers at the Success Mine Site.

Gravel was added in 2001 to help control plugging. This provided only a short benefit and plugging was again an issue. The INL received funding in 2003 to assist the Coeur d'Alene Basin Commission in remediating the plugging issues associated with the reactive barrier. Chemical and biochemical analysis was performed on the media to determine the forms of metal precipitates, biological conditions, and physical and chemical conditions of the media.

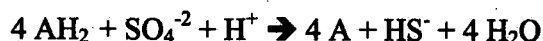
In May of 2005, the compressed air was injected into the Apatite IITM to break up sediments deposited in the media in order to increase flow through the media. MSE Technology Applications, Inc., in Butte, Montana had demonstrated that injecting air into a similar reactive barrier at the Stewart Mine on Pine Creek had successfully increased flow in the Apatite IITM media at that location (McCloskey et al., 2006).

In November 2005, the old gravel/ Apatite IITM mixture was removed and disposed onsite to make room for the new Apatite IITM /plastic packing ring mixture. New Apatite IITM media mixed with plastic packing rings was used to replace the plugged media in the East side of the reactive barrier. The plastic packing rings were used to increase the void space in the media and alleviate the plugging problem.

Material and Methods

Biological Analysis of the Apatite IITM Media

The Apatite IITM media was sampled to determine if sulfate reducing bacteria (SRB) were active in the barrier. These bacteria are responsible for precipitating metal ions found in acid mine drainage. SRBs are a ubiquitous group of prokaryotic microorganisms found in anaerobic environments. In the process of anaerobic respiration these organisms can use a variety of electron donors (AH₂) and can couple oxidation of those compounds to reduction of sulfate and elemental sulfur as shown in the following equation:



It is in the anaerobic zone that the remediation takes place. The sulfide produced then precipitates with the soluble metals (such as Fe, Cu, Mn, Zn, Pb, and Cd) as insoluble metal sulfides, and the net consumption of protons due to formation of hydrogen sulfide gas generates bicarbonate alkalinity, which raises the pH of the waste stream.

The media used to isolate and identify SRB was Bacti control bottles API Anaerobic media which includes ammonium phosphate, dipotassium phosphate, yeast extract yeast extract, sodium lactate and magnesium sulfate and a nail to provide iron manufactured by Sherry Laboratories. Water samples were collected from each cell in both sides of the reactive barrier and from the outflow. One mL of each water sample was injected into a Bacti vial, using sterile methods. Each sample was collected in triplicate and diluted out to 10⁻⁸. Medium used for heterotrophic and enteric bacteria was 2% PTYG Agar (2% Peptone-Tryptone-Yeast Extract-Glucose and 1.5 % agar) and Luria-Bertani Agar (10 g tryptone, 5 g yeast extract, 5 g NaCl, and 15 g agar per liter of water). One mL and 0.1 mL samples were plated in duplicate on both medium. Eh and pH of water samples were also taken.

Chemical Analysis of the Apatite IITM Media

Apatite IITM samples were collected from below the water level in each side of the reactive barrier to be representative of the conditions where chemical and biological reactions occur. The samples were collected and stored in polypropylene containers and put on ice until they were received at the laboratory.

Both the sediments and the Apatite IITM were oven dried for 24 hours at 90° C. The samples were sieved to separate the sediments from the Apatite IITM media. The Apatite IITM media was also washed with tap water (tap water) to remove any surface attached material from the fish bones. The samples were pulverized with a mortar and pestle in preparation for analysis. The samples were analyzed for both metal concentrations and speciation using Powder X-Ray Diffraction and XRF and by Scanning Electron Microscopy.

Injection of Compressed Air to Improve Flow

The covers to the reactive barriers were removed to provide access to the media. A 10 foot galvanized hollow wand was fabricated to inject compressed air deep into the media. Compressed air was injected in at least two locations in each of the 5 cells for both the East and West side of the reactive barrier (See Figure 3).



Figure 3. Injecting Compressed Air in the Apatite IITM Media.

Replacing the Media in the Reactive Barrier with Apatite IITM and Plastic Packing Rings

Attempts to improve flow on the East side of the reactive barrier were only temporarily successful. The addition of gravel to the media did not improve flow through the system. Aerating the Apatite IITM media was successful for a short time, but it soon returned to the original flows. As a result, an alternative mixture of Apatite IITM and plastic packing rings was used to help increase the percent of void space in the reactive barrier. Plastic packing rings (produced by Jaeger Products Inc.,) are used in many aspects of water treatment to increase the

surface area for microbial attachment and increase the reactive area of the media. They are also used to increase the void space in the media (Figure 4).

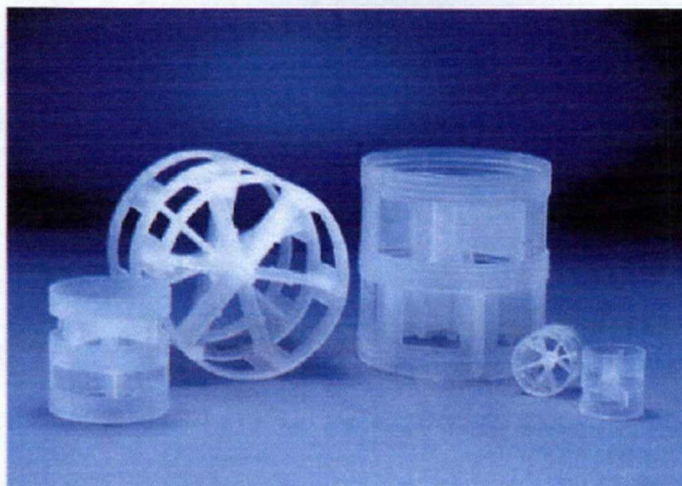


Figure 4. Plastic Packing Rings.

Results and Discussion

Water samples were taken at the discharge of both sides (East and West) of the reactive barrier to determine if SRBs were present in the discharge. Water was also sampled in each of the 5 cells on each side of the reactor. The Apatite IITM was plugged on the East side and required mechanical mixing and injection of compressed air to get water flowing again through the reactive barrier. This would have affected the true Eh values being measured in the field at the time. Table 1 shows the results of the field measurement for pH and Eh and Table 2 shows the laboratory results for the SRB counts.

Table 1. Field Measurements for Eh, pH, and SRB Counts.

Sample	Eh	pH
Inflow water	468	4.5
Cell 1 West	211	7
Cell 2 West	-48	6
Cell 3 West	245	6
Cell 4 West	238	6
Cell 5 West	-199	7
Outflow West	150	7
Cell 1 East	236	6
Cell 2 East	310	6
Cell 4 East	Not sampled	Not sampled
Cell 5 East	Not sampled	Not sampled
Outflow East	224	7
E.fork Nine Mile Creek	550	

Table 2. Sulfate Reducing Bacteria Counts.

Sample	Sulfate Reducing Bacteria
Cell 1 West	3×10^4 /mL
Cell 2 West	3×10^4 /mL
Cell 3 West	4×10^4 /mL
Cell 4 West	4×10^3 /mL
Cell 5 West	7×10^5 /mL
Outflow West	1×10^2 /mL
Outflow West	present
Cell 1 East	1×10^5 /mL
Cell 2 East	7×10^3 /mL
Cell 3 East	Not Done
Cell 4 East	1×10^3 /mL
Cell 5 East	7×10^3 /mL
Outflow East	1 /mL
Outflow East	Present

The most obvious finding is that there was in fact SRBs present in the reactive barrier as expected, so some treatment (precipitation) of should occur. The Eh values indicate that most samples are not anaerobic (negative value). This is probably due to the low levels of water in the barrier, which was a consequence of the time of year and weather conditions. Several locations in the West cells had negative Eh values, indicating that the water was deep enough in the barrier and anaerobic activity was present. However, not all location in the West cells had negative Eh values. The micro anaerobic zones did exist throughout the barrier, as shown by the presence of SRB's in most samples. If more water was present in the barrier, a larger anaerobic zone could be created and a larger population of SRB would be present (1×10^8 /mL). This would hopefully lead to complete precipitation of the metal and an increase of the pH to neutral (7.0). The East cells had little to no water flow and no anaerobic zones as indicated by the positive Eh values. It is not likely that treatment was occurring in this cell. If flow can be maintained, and anaerobic zones created, SRB should grow and metal precipitation and pH increase should occur.

Chemical Analysis of the Apatite IITM Media

The presence of zinc, cadmium and lead were measured in the Apatite IITM using scanning electron microscopy (SEM). The SEM provided a relative concentration for each metal. Figure 5 shows the relative weight percents observed in the Apatite IITM for each of the metals of concern. In addition, the concentration of sulfur was also measured. Sulfate is present in the feed water. Under anaerobic conditions, the metals form insoluble sulfide precipitates. The presence or absence of sulfur can be used to determine if metal sulfides are being formed under the conditions present in the reactive barrier. In the Apatite IITM samples, there was no appreciable amount of sulfur detected (Figure 5).

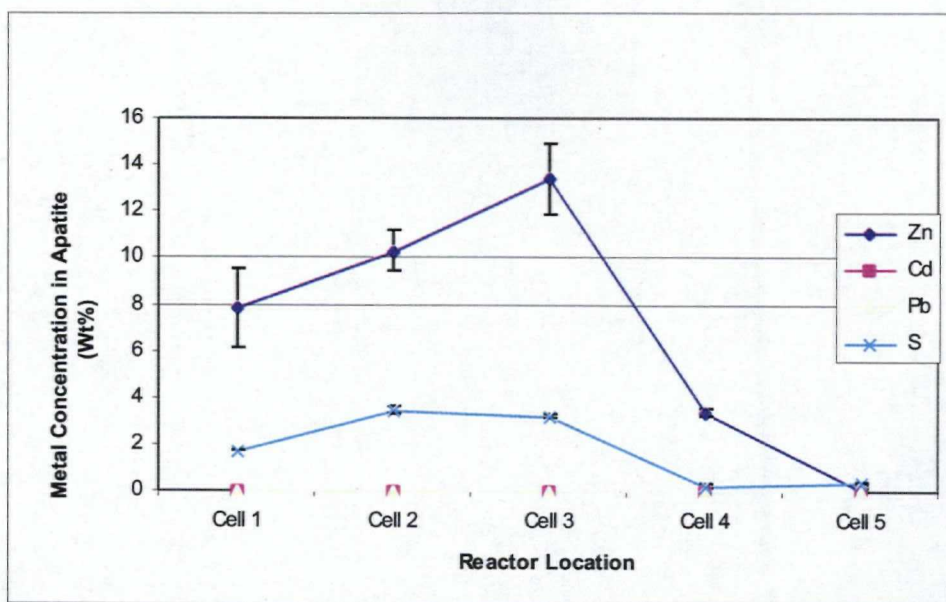


Figure 5. Metal concentration in the Apatite IITM material from the West Side of the Reactive Barrier.

The sediments around the Apatite IITM were also analyzed for metal concentration. Slightly higher concentrations of zinc and lead were present in the sediment than in the Apatite IITM. There was also a notable amount of sulfur present in the sediment. This suggests that the metal precipitates formed in the sediments were resulting at least in part due to metals sulfides being formed under anaerobic conditions.

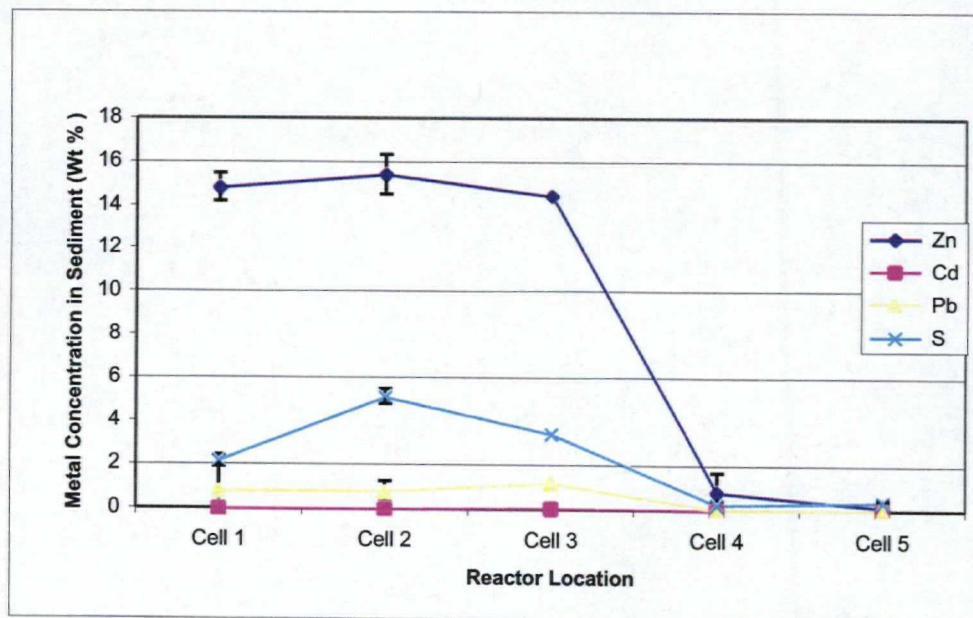


Figure 6. Metal concentrations in the sediment of the West Reactive Barrier.

The same analysis was performed on the East side of the reactive barrier. Figure 7 shows the zinc, cadmium, lead and sulfur concentrations found in the Apatite IITM from the East side of the reactive barrier. This figure shows that the concentrations of the contaminant metals were lower in the East side than the West side. It also shows that most of the reaction occurs in the first two cells and that the subsequent cells are not removing metal from the contaminate water.

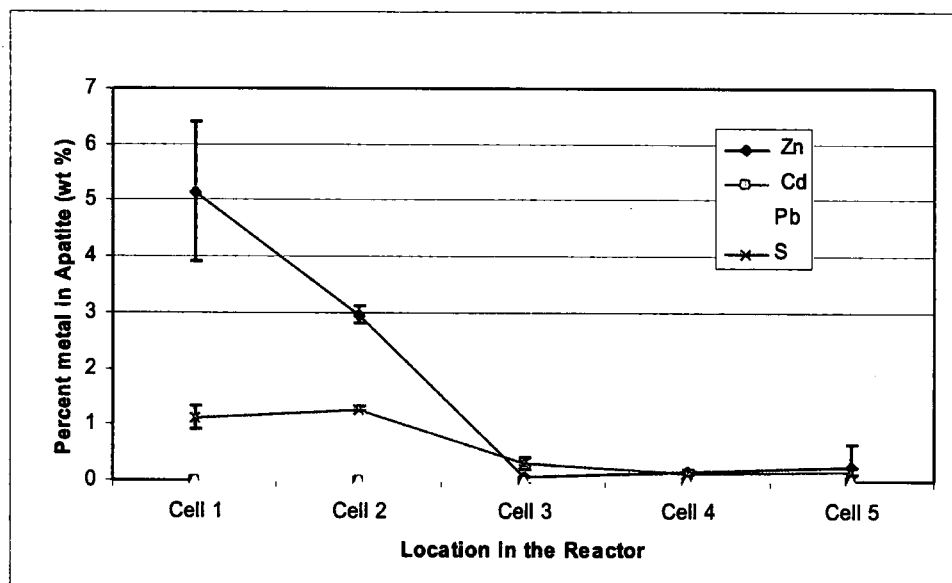


Figure 7. Metal concentration in the Apatite IITM from the East side of Reactive Barrier.

Figure 8 illustrates the concentrations of the metals of interest in the sediment of the East side of the reactive barrier. Most of the precipitation that does occur, takes place within the first two cells of the barrier. The concentration is about half the measured values observed in the West side of the reactive barrier.

Injection of Compressed Air

The reactive barrier was constructed in 2000 and the first Apatite IITM was placed in the barrier in January of 2001. Other than adding new media to the East side of the reactive barrier in 2002, nothing had been done to deal with the plugging issues associated with the reactive barrier. The cause of the plugging was a combination of sediment buildup from the influent stream and sedimentation occurring from the breakdown of the Apatite IITM. Figure 9 illustrates the sediment buildup that had occurred in the West side of the reactive barrier. Note the buildup of sediment in the Apatite IITM and notice how the water has formed preferential paths in the media resulting in inefficient contact of water and the reactive media.

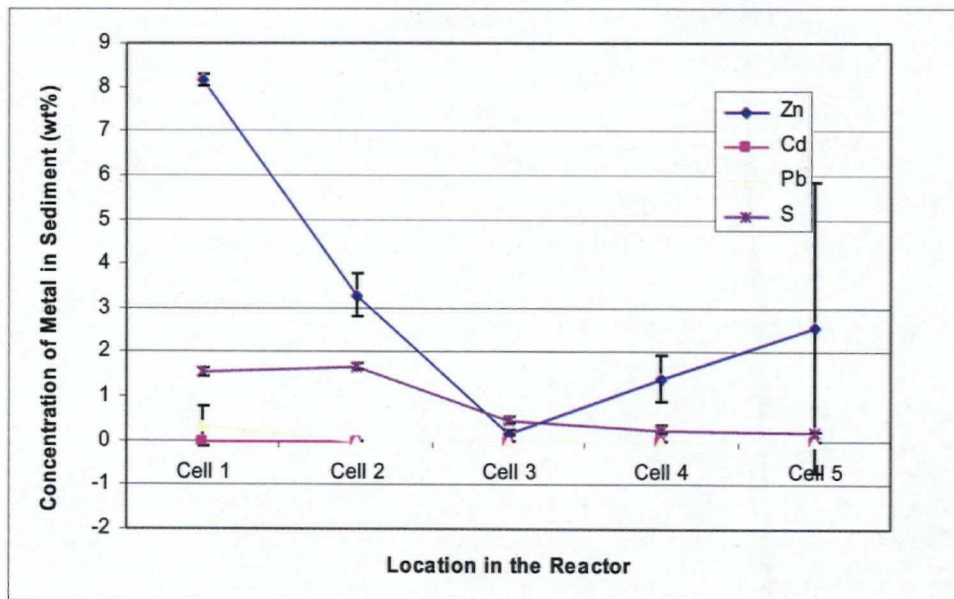


Figure 8. Metal Concentration in the Sediment of the East side of the reactive barrier.

Another similar site in the Coeur d'Alene basin is using Apatite IITM to treat acid mine drainage at the Nevada Stewart Mine. At this location, compressed air is injected into the media combat the effects of plugging on the reactive barrier. This results in temporarily increased flow in the media at the Nevada Stewart Mine site. For the reactive barrier at Success, a ten-foot hollow wand was constructed to inject air deep into the media at the Success Mine reactive barrier. Figure 10 shows the workers injecting air into the media at the Success Mine.



Figure 9. Sediment buildup in the Reactive Media.



Figure 10. Injection of Compressed Air into the Reactive Media.

The result of the injection of compressed air into the media was an immediate increase in flow through the reactive barrier, primarily on the West side. The presence of the gravel on the East side made it difficult to get the metal wand into the media to successfully inject the air into the media. This resulted in only limited success on the East side of the reactive barrier.

Figure 11 shows the flow rate measured at the discharge of the reactive barrier. Note that before injecting air into the reactive media, there was a steady stream of water measured in the overflow for the system. Following the air injection, the flow through the reactive media increase and the overflow went to zero meaning that the system was again treating all of the water. The flow rates in general continued to decrease over time following the air injection, but this is primarily due to a seasonal decrease in flow. Note that there was no flow observed in the overflow following the air injection and that the flow in the West side increased again in the Spring of 2006 when flows came back up. Flow on the East side also increased at that time, but it should be noted that the increase in flow on the East side could be directly attributed to the addition of new media in November of 2005. From this it can be observed that injecting compressed air into the media does provide at least temporary improvement to flow in the Apatite IITM media.

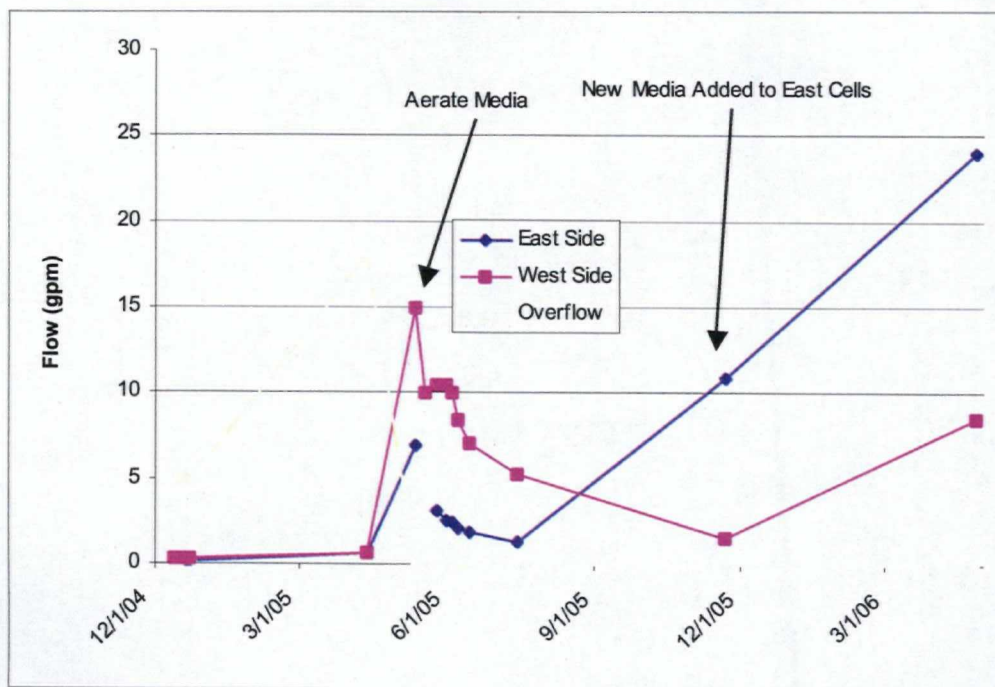


Figure 11. Flow rates measured in the outlet and overflow of the reactive barrier.

Replacing the Media in the Reactive Barrier with Apatite II™ and Plastic Packing Rings

In November of 2005, the media in the East side of the reactive barrier was replaced with new Apatite II™ mixed with plastic packing rings at a ratio of 30 volume % plastic packing rings. Two inch Jaeger plastic packing rings were used to provide an increase in void volume in the reactive barrier. The increase in void volume was desired to provide more area for water to flow through in the Apatite II™ media and to provide more volume for sediments and precipitates to form without impacting the flow. Figure 4 is a picture of the packing rings used in the reactive barrier. By themselves, the plastic rings have a void volume of 92%. Information on the void space of Apatite II™ was not available, but had noticeably less void volume than the plastic rings alone.

Prior to the removal of the old Apatite II™ /gravel mixture and the placement of the new Apatite II™ /plastic packing ring mixture, the flow from the East side of the reactive barrier was less than 1.5 gallons per minute. After replacing the media, the flow increased to over 10 gallons per minute in December of 2005. It further increased to 24 gallons per minute in April of 2006 (primarily due to high Spring water runoff). This is the highest flow produced from the East side of the reactive barrier since it was constructed. In June of 2006 the flows had gone back down to just over 5 gallons per minute, but there was no water flowing out the overflow. This still was the highest flow from the East side of the reactive barrier since May of 2002. Figure 12 illustrates the flow rates through the reactive barrier since it was constructed. Since the change out of the

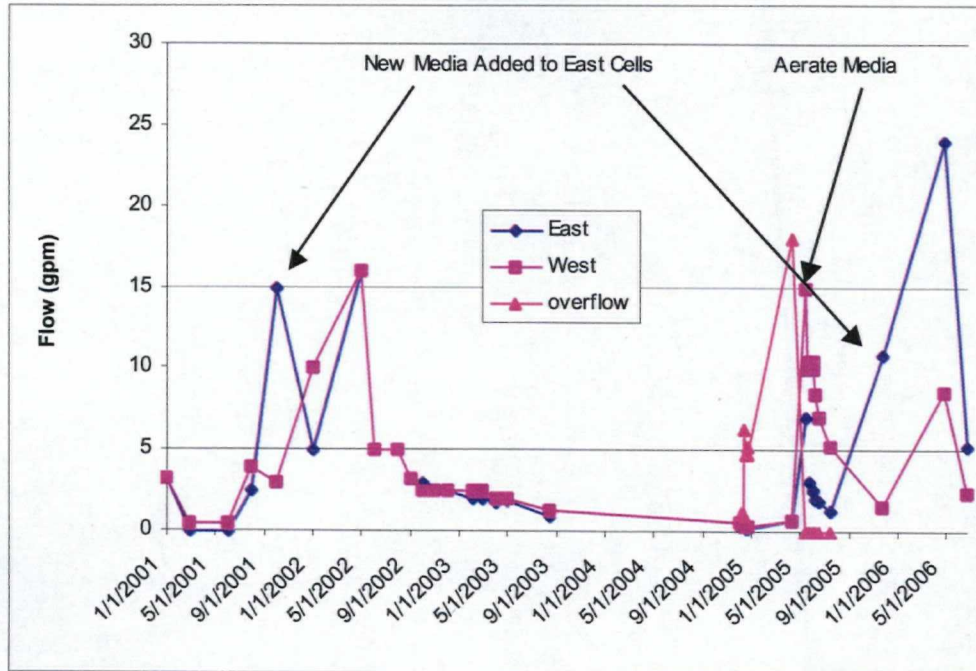


Figure 12. Flow rate (gallons per minute) for the Success Reactive Barrier.

*data from 1/1/2001 to 9/1/2003 was taken from Golder 2003 – overflow data was not always collected

media in the fall of 2005, the East side of the reactive barrier has produced higher discharge flow rates than the West side of the reactive barrier for a longer period of time since the barrier was constructed.

Ph was measured from November 2004 through September of 2005. The pH of the water has been improved by treatment with the Apatite II™ media. Influent pH levels average 4.8. Effluent pH values average 6.7 in the West side of the reactive barrier and 6.6 from the East side of the reactive barrier.

Removal efficiency

The average concentration of the metals of concern in the influent to the reactive barrier are 0.52 mg/L Cd, 1.01 mg/L Pb, and 83.6 mg/L Zn. The average concentration in the discharge for the West side of the reactive barrier is 0.007 mg/L Cd, 0.014 mg/L Pb, and 1.06 mg/L Zn. On the East side of the reactive barrier the outlet average outlet concentration is 0.002 mg/L Cd, 0.005 mg/L Pb, and 0.374 mg/L Zn. The removal efficiencies for the metals are presented in Figure 13. In each case, the removal efficiency is greater than 98% removal.

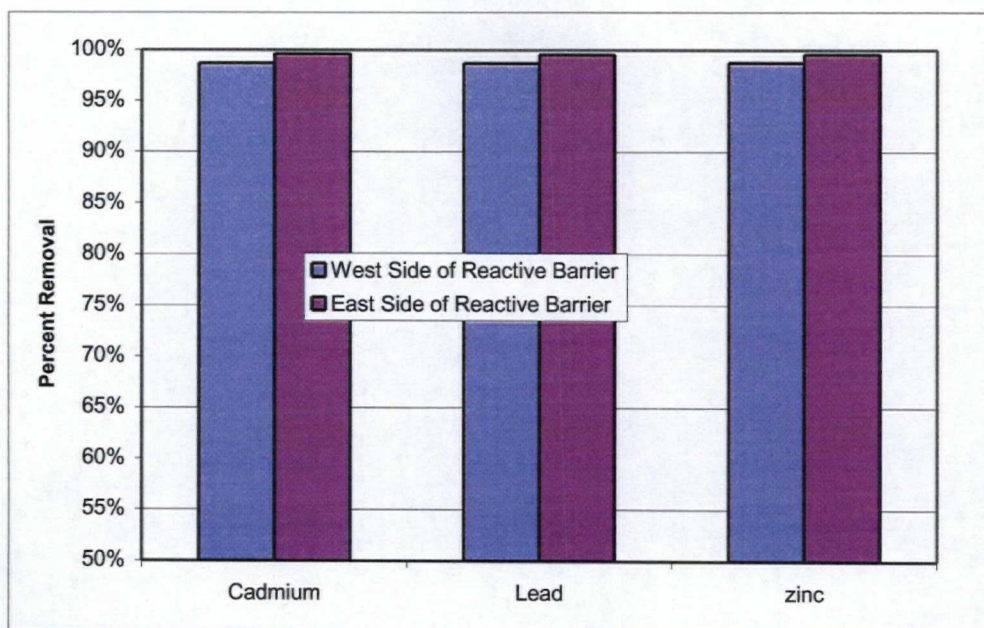


Figure 13. Removal Efficiency for Cd, Pb, and Zn from the Reactive Barrier.

Summary

The biological and chemical analysis of the Apatite IITM showed that the reactive barrier is utilizing more than one single method to remove metal contaminants from the mine drainage, specifically both biological reduction and chemical sorption are causing the reduction in metal concentrations in the contaminated waters.

The injection of compressed air does improve the performance of the reactive barrier by breaking up preferential flow paths created over time in the media. The process of injecting compressed air will need to be reviewed on a case-by-case basis, but in this case annual injection of air would lengthen the life of the media.

Since the construction of the reactive barrier in 2001, the media in the East side of the reactive barrier has been replaced twice. It is not clear why the problem started so early on in the system when both sides of the barrier appeared to have been constructed in the same manner. It is apparent that mixing the Apatite IITM with gravel does not improve the efficiency of the system. Two problems resulted from this. First, the addition of gravel to the Apatite IITM did not have the desired effect of increasing the void space of the media; it simply reduced the amount of media present. Second, it created a media with a much higher bulk density. The two sides appear to have similar void volumes. Water entering the two sides of the reactive barrier enters from the same distribution box or manifold. Water naturally tends to flow to the path of least resistance which in this case is the side without the gravel.

Since the new Apatite II™ mixed with plastic packing rings was put in the East side of the reactive barrier in November 2005, the flows in the East side of the reactive barrier have surpassed the West side for the longest period of time since construction. While continued monitoring needs to take place, we are optimistic that this will be a beneficial solution to the plugging experienced at the Success Mine.

Using the average flow rates and average concentrations in the source water and the treated water, it is estimated that the system has removed 44 pound of cadmium from the East side and 49 pounds of cadmium from the West side of the reactive barrier, 85 pounds of lead from the East side and 95 pounds of lead from the West side of the reactive barrier, and 7003 pounds of zinc from the East side and 7850 pounds of zinc from the West side of the reactive barrier over the 5 years of operation. While this paper discusses resolving plugging issues with the Apatite II™ media, it should be noted that the systems has continued to successfully reduce metal concentrations in acid mine drainage to below drinking water standards and raise the pH to near neutral levels. With the addition of the plastic packing rings to the Apatite II™, it is anticipated that the system will continue to operate for several more years.

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APPENDIX G
Aquifer Test Data [GeoSyntec, 2000]

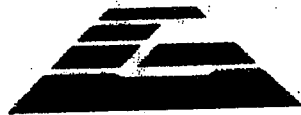
Prepared For:

INTERIM PEDRICKTOWN SITE GROUP

**PHASE II
GROUNDWATER EVALUATION
TECHNICAL MEMORANDUM**

**NL INDUSTRIES, INC.
SUPERFUND SITE
PEDRICKTOWN, NEW JERSEY**

Prepared By:



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Columbia, Maryland 21046

**Project Number ME0015-15
January 2000**

9. AQUIFER TEST

9.1 Overview

In 1983, Geraghty & Miller performed an aquifer test at the NL site. The EPA questioned some of the techniques used in Geraghty & Miller's evaluation and required the Group to perform an aquifer test. This section includes a description of the aquifer test performed in June 1999 by GeoSyntec. The aquifer test was conducted to:

- (i) confirm the hydraulic parameters determined by Geraghty & Miller in 1983;
- (ii) predict the performance of a groundwater extraction system that might be designed to remove lead and cadmium from the aquifer; and
- (iii) establish input parameters for capture zone modeling as requested by the EPA.

Aquifer parameters have been estimated based on the results of the aquifer test completed in June 1999. Standard analytical methods were employed in the analysis of the aquifer test data to determine transmissivity, hydraulic conductivity, and storativity. AQTESOLVTM for WindowsTM (HydroSOLVE, Inc., 1999) was used to perform the analyses. The hydraulic parameters, combined with other site-specific data such as average grain size, depth to the underlying clay layer, saturated thickness, etc., were used to refine the conceptual hydrogeologic model of the site originally presented in the *Phase I Groundwater Evaluation Technical Memorandum*.

The aquifer testing included ambient water-level monitoring, a variable-rate pumping test (step test), and a 72-hour constant-rate pumping test. Groundwater was pumped from pumping well PW, a six-inch diameter, fully-penetrating well installed and developed for the conduct of this aquifer test. Drawdown was measured in several nearby wells throughout the testing process, including observation well OW, the nearest well to pumping well PW. The relative locations of PW, OW, and all other observation wells used during the test are presented on Figure 9-1. Boring logs are provided in Appendix A for each of the new wells at the site. The following subsections describe the aquifer testing procedures and present the analysis of the results.

9.2 Procedures

9.2.1 Ambient Water-Level Monitoring

Prior to the on-set of aquifer testing, passive water-level monitoring was conducted using PXD-60 pressure transducers and a Hermit datalogger manufactured by In-Situ, Inc. This monitoring was conducted for approximately 13 days beginning on 20 May 1999 and measurements were collected once per hour. Measurements were obtained from six wells including: PW, OW, 27, 28, KS, and KD. Figure 9-2 shows a hydrograph throughout the 13-day monitoring period at observation well OW. After approximately 95 hours of monitoring, at approximately 12:30 p.m. on 24 May 1999, the water level began to rise in Well OW, increasing approximately one foot over a 13-hour period. This increase in water level was also evident in the other wells monitored. This rise was coincident with an 11-hour precipitation event that included more than two inches of rain over the area (precipitation data derived from Wilmington, Delaware weather station, NOAA, 1999). Following the peak water level, the head in the wells gradually declined toward the seasonal low, approaching static conditions just prior to the step test.

GeoSyntec obtained additional ambient water-level data after the step test and constant-rate test were completed to further evaluate the characteristics of the aquifer. This monitoring began on 23 July 1999 and continued through 9 August 1999. The hydrograph for pumping well PW is shown on Figure 9-3. The graph indicates a steady decline in the water table as no precipitation occurred during the monitoring period. The decline is approximately 0.04 feet per day, with diurnal fluctuations of approximately 0.02 feet. The diurnal peaks generally occur between 3:00 and 4:00 am and the diurnal troughs generally occur between 8:00 and 10:00 p.m. Figure 9-4 shows the first 4,500 minutes of this monitoring period in greater detail.

9.2.2 Step Test

After obtaining the pre-test ambient water-level data, a step test was conducted on 2 June 1999 in pumping PW. This step test was performed to determine an optimal pumping rate for the subsequent constant-rate test by measuring the pumping rate and drawdown and establishing a rate that adequately stressed the aquifer without dewatering the well. A submersible centrifugal pump, powered by a portable 440 amp generator was used. Pumped water was conveyed to a 20,000 gallon portable tank, and the pumping rate was determined with a graduated, five-gallon bucket and a stop watch.

Seven steps were conducted over a period of approximately 200 minutes. Figure 9-5 shows the hydrograph at PW during the step testing and a table of respective pumping rates. Based on the results of the test, a target pumping rate of approximately 20 gallons per minute (gpm) was selected for the constant-rate test. Appendix G contains the raw transducer data from the step test.

9.2.3 Constant-Rate Test

On 7 June 1999, a 72-hour constant-rate pumping test (CRT) was conducted at pumping well PW. Pumping-rate determination, water containerization, and water-level measurement procedures were similar to those used during the step test. In addition, a total of 33 site wells were monitored with portable water-level indicators (WLIs) to calibrate the datalogger and to serve as a backup in the event of datalogger/transducer failure. Appendices H and I contain tabulated data from the datalogger and WLIs, respectively. Prior to the onset of pumping, static water level elevations were determined for each of the wells monitored throughout the aquifer testing (Figure 9-6). The map includes only those wells screened within the upper portion of the unconfined aquifer. Some wells, such as HS and 22 are excluded from the map because they are screened in clay. The water levels measured throughout the testing period are summarized on Table 9-1.

9.3 Evaluation and Results

9.3.1 Hydraulic Analysis

Figure 9-7 shows the hydrograph of observation well OW throughout the testing period. The hydrograph depicts a rapid drop in water level at the start of the constant rate test with minor fluctuations caused by minor adjustments in the pumping rate, followed by steady drawdown over a period of approximately one day. After approximately 1,500 minutes of pumping, the portable generator failed and pumping ceased for 68 minutes until a replacement generator could be brought on-line and the test resumed. Slight fluctuations in the data are evident as the pumping rate was adjusted to original pumping conditions. The maximum fluctuation in pumping rate was 10 percent, and generally, the pumping rate varied by only five percent. Variations occurred only over short periods during the test; therefore, the resultant data are valid for the hydraulic evaluation. The average pumping rate throughout the entire 72-hour period was 18.75 gpm.

Figure 9-8 is the same hydrograph shown on Figure 9-7, but it is extended to show the aquifer recovery following the CRT and includes barometric pressure data collected during the same period. Barometric pressure is monitored during pumping tests to determine the influence, if any, of fluctuating atmospheric pressure on the potentiometric surface in the aquifer. Such an effect is primarily observed in confined aquifers, but prudent practice dictates the monitoring of barometric pressure during all aquifer tests. If an effect is seen, the barometric efficiency of the well is calculated and the drawdown data are adjusted accordingly. For this test, a barometric pressure transducer was connected to the datalogger to record pressure in feet. As shown on Figure 9-8, and as expected for an unconfined aquifer, there was no observed barometric effect on the water table and adjustments were not necessary. The small peak in the recovery data at approximately 11,000 minutes after the start of the CRT resulted when water containerized during the test was released. Figure 9-9 depicts the potentiometric surface on 10 June 1999 near the end of the pumping test.

The drawdown data indicate a delayed-yield response typical of unconfined aquifers. Figure 9-10 shows one example of this response. In Segment 1 of Figure 9-10, the data initially reveal a drawdown curve similar to that expected from a confined aquifer, because water is being released from the elastic storage of the aquifer, not from the pore spaces of the aquifer. Thereafter, in Segment 2, the drawdown rate decreases and the data reveal a more gradual curve as gravity drainage contributes water that was previously held in storage (i.e., within the pore spaces of the sand grains). Eventually, as in Segment 3, the effects of gravity drainage are diminished as the aquifer becomes unsaturated above the cone of depression. Neuman (1974) devised an analytical solution for unconfined aquifers with delayed gravity response. Use of this solution provides estimates of transmissivity, storage coefficient, specific yield, and Beta, a term that relates the aquifer anisotropy and radial distance to the observation well.

Figures 9-11, 9-12, and 9-13 are AQTESOLV™ for Windows™ results of Neuman solutions conducted on drawdown and recovery data from Wells OW, KD, and 28, respectively. Because AQTESOLV™ incorporates the principle of superposition in the analysis to accommodate variable pumping rates (Streltsova, 1988), it is possible to combine both drawdown and recovery (including the short stoppage in pumping when the generator failed) at a well in one solution. Prior to analysis, late drawdown data were corrected for dewatering using Jacob's correction method (Jacob, 1944). The results of the analyses shown on Figures 9-11, 9-12, and 9-13 are summarized below.

Well	T (gpd/ft)	S	Sy	B	b (ft)	k (gpd/ft ²)
OW	3800	5.03E-04	4.69E-02	4.30E-03	23	165
28	4200	1.60E-03	2.29E-02	2.70E-01	18	233
KD	4300	2.40E-04	1.00E-02	1.33E-02	23	187
Mean	4100	7.81E-04	2.66E-02	9.59E-02	21	195

Notes: T = Transmissivity
 S = Storativity
 Sy = Specific yield
 B = Beta
 b = Aquifer thickness
 k = Hydraulic conductivity

The results indicate a relatively transmissive aquifer, with: (i) an average transmissivity of approximately 4,100 gpd/ft; (ii) a storativity of 8×10^{-4} during the earliest portion of the data, a result that is reasonable for the segment of the test that exhibits a confined aquifer response; and (iii) a specific yield (equivalent to storativity near the end of the test) of approximately 3×10^{-2} , a result that is a reasonable storativity estimate for an unconfined aquifer. At an average saturated thickness of 21 feet, these results yield a hydraulic conductivity estimate of approximately 195 gpd/ft² or 26 ft/day. These results are similar to the results obtained previously by Geraghty & Miller.

9.3.2 Chemical Analysis

Throughout the CRT, pH and turbidity were monitored. These results are presented on Table 9-2. In addition, groundwater samples were obtained from the pumping well and analyzed for lead, cadmium, VOCs and general chemical parameters. The results of the chemical analyses of groundwater samples obtained from pumping well PW during the CRT are summarized on Tables 9-3 through 9-5. Trace concentrations of VOCs were detected. The data for lead, cadmium, pH, and turbidity were plotted with time on Figures 9-14 through 9-17. As indicated on Figures 9-14 through 9-17, the concentrations of lead and cadmium in the extracted groundwater were low, relative to the ambient concentrations of lead and cadmium in the groundwater where the extraction well is located. More significantly, the concentrations of lead and cadmium declined during the test. For lead, the concentration was below the level of detection during most of the test. On one occasion, the generator supplying power to the pump stopped. Upon restarting the generator and pump, an increase in turbidity and lead concentration occurred briefly. Thereafter, the flow rate of the pump was altered slightly several times, which also

resulted in minor variations in turbidity and lead concentrations (Figures 9-14 and 9-15).

For cadmium, a steady decline in concentration was noted during the aquifer test. It is anticipated that the concentration of cadmium could have declined to below the level of detection within 12 to 15 days of pumping. However, because the test was performed for only three days, the time required for the concentration of cadmium to decline to the detection level is estimated.

9.3.3 Anticipated Extraction of Lead and Cadmium

When groundwater is extracted for an extended period, the concentrations of any constituents either dissolved in groundwater or entrained in the flow of groundwater tend to asymptotically decline to a minimum as geochemical reactions and dilution occur. In this case, the level to which the concentration of lead is expected to decline is below the level of detection. It is also anticipated that for cadmium, the concentration will be at or below the detection level. Under a long-term pumping scenario, the concentration of inorganics such as lead and cadmium in extracted groundwater may be significantly lower than the respective detection levels.

Assuming that 1 ppb of lead could be extracted continuously at an estimated flow rate of 37 gpm (Section 10) it is estimated that approximately 60 years of pumping would be required to extract a significant amount of the lead remaining in groundwater (Table 9-6). For cadmium, assuming the same extraction rate and an average concentration of 2 ppb in the extracted groundwater, it is estimated that 50 years of pumping would be required to extract a significant mass of the cadmium remaining in groundwater (Table 9-6). These timeframes are theoretical. Achievement of RAOs may occur in shorter periods as a result of the naturally occurring improvement of groundwater quality described above. Therefore, it is expected that extracting small amounts of lead and cadmium through the use of the pump-and-treat technique will not significantly enhance improvement of groundwater quality.

As described in Section 12, the results of modeling confirm that extracting significant amounts of lead and cadmium from the aquifer is infeasible. In fact, extracting lead and cadmium by pumping groundwater is so ineffective that it will not contribute significantly to achievement of RAOs. Therefore, the implementation of a pump-and-treat remedy for this site is impractical.

GROUNDWATER LEVELS PRIOR TO AND AFTER COMPLETION OF THE PUMPING TEST

Phase II Groundwater Evaluation
 NL Industries Superfund Site
 Pedricktown, New Jersey

PRE-TEST GROUNDWATER ELEVATIONS 6/7/99 BETWEEN 1300 AND 1400 HRS.				PUMPING-TEST GROUNDWATER ELEVATIONS 6/10/99 BETWEEN 1300 AND 1400 HRS.				DIFFERENCE		DRAWDOWN	
WELL	TOC (ft)	DTW (ft)	GW ELEV (ft)	WELL	TOC (ft)	DTW (ft)	GW ELEV (ft)	(ft)		(ft)	
SD	13.39	7.15	6.24	SD	13.39	8.17	5.22	1.02		1.02	
SS	12.7	6.11	6.59	SS	12.7	7.01	5.69	0.9		0.9	
S4-1*	12	5.2	6.8	S4-1*	12	6.2	5.8	1		1	
T2-3	11.34	6.76	4.58	T2-3	11.34	7.02	4.32	0.26		--	
TC	--	7.25	--	TC	--	7.55	--	--		--	
T-4	12.12	7.31	4.81	T-4	12.12	7.66	4.46	0.35		--	
T-A	--	7.58	--	T-A	--	7.96	--	--		--	
OS	11.95	7.63	4.32	OS	11.95	7.96	3.99	0.33		--	
OD	12.47	8.33	4.14	OD	12.47	8.58	3.89	0.25		--	
II	11.19	5.41	5.78	II	11.19	5.6	5.59	0.19		--	
PD	12.86	6.85	6.01	PD	12.86	7.09	5.77	0.24		--	
BR	10.82	5.5	5.32	BR	10.82	5.74	5.08	0.24		--	
PS	11.89	5.72	6.17	PS	11.89	5.96	5.93	0.24		--	
PW	11.55	6.18	5.37	PW	11.55	14.5	-2.95	8.32		8.32	
OW	11.83	6.49	5.34	OW	11.83	9.51	2.32	3.02		3.02	
KS	11.54	6.04	5.5	KS	11.54	8.77	2.77	2.73		2.73	
KD	11.77	6.27	5.5	KD	11.77	9.27	2.5	3		3	
24	13.04	17.56	-4.52	24	13.04	17.92	-4.88	0.36		--	
JD	14.02	7.48	6.54	JD	14.02	7.91	6.11	0.43		--	
JS	13.89	7.38	6.51	JS	13.89	7.82	6.07	0.44		--	
10R	14.02	17.31	-3.29	10R	14.02	17.67	-3.65	0.36		--	
ID	17.18	10.55	6.63	ID	17.18	10.83	6.35	0.28		--	
IS	17.35	8.19	9.16	IS	17.35	8.43	8.92	0.24		--	
HD	18.67	13.65	5.02	HD	18.67	13.89	4.78	0.24		--	
HS	18.4	13.8	4.6	HS	18.4	14.03	4.37	0.23		--	
28	16.4	10.92	5.48	28	16.4	11.96	4.44	1.04		1.04	
27	16.57	11.07	5.5	27	16.57	12.03	4.54	0.96		0.96	
30	16.29	11.13	5.16	30	16.29	11.36	4.93	0.23		--	
29	16.26	10.79	5.47	29	16.26	11.1	5.16	0.31		--	
32	14.28	9.77	4.51	32	14.28	9.97	4.31	0.2		--	
31	14.33	9.21	5.12	31	14.33	9.4	4.93	0.19		--	
RD	15.56	9.58	5.98	RD	15.56	9.77	5.79	0.19		--	
RS	15.4	7.42	7.98	RS	15.18	7.57	7.61	0.37		--	

Notes

1) TOC for Wells PW, OW, OS, OD, KS, KD, HS, HD, SS, T-4, RS, RD, PS, 24, 28, 27, 30, 29, 32, and 31 adjusted by adding 1.12 feet to convert from NAVD 1988 to NGVD 1929

2) Shaded cells denote wells used in construction of shallow potentiometric surface maps and flow model

3) Water-level differences less than 0.2 feet are attributed to the natural decline of the water table during the 1999 drought and do not represent drawdown

* TOC is estimated

TABLE 9-2
SUMMARY OF GROUNDWATER pH and TURBIDITY⁽¹⁾
DURING AQUIFER TEST

Phase II Groundwater Evaluation
NL Industries Superfund Site
Pedricktown, New Jersey

Sample Designation	Date	Time	Turbidity ⁽²⁾	pH ⁽³⁾
PT-1-060799	06/07/1999	1500	1.40	3.23
PT-2-060799	06/07/1999	1537	0.60	3.11
PT-3-060799	06/07/1999	1630	NT	3.58
PT-4-060799	06/07/1999	1730	0.85	3.15
PT-5-060899	06/08/1999	130	0.30	3.69
PT-6-060899	06/08/1999	930	0.67	3.41
PT-7-060899	06/08/1999	1720	0.86	3.2
PT-8-060999	06/09/1999	1330	0.94	2.94
PT-9-060999	06/09/1999	1020	0.87	3.32
PT-10-060999	06/09/1999	1750	0.92	3.25
PT-11-061099	06/10/1999	130	0.00	3.11
PT-12-061099	06/10/1999	930	1.38	3.28
PT-13-061099	06/10/1999	1415	1.90	3.15

TABLE 9-3

**SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED
DURING AQUIFER TEST**

**Phase II Groundwater Evaluation
NL Industries Superfund Site
Pedricktown, New Jersey**

Sample Designation	Date	Time	Chloroform, ug/L	Toluene, ug/L
PT-1-060799	06/07/1999	1500	0.23 J	0.17 J
PT-8-060999	06/09/1999	1330	0.25 J	0.25 J
PT-13-061099	06/10/1999	1415	0.19 J	ND
TRIP BLANK	06/09/1999	NA	ND	ND
TRIP BLANK	06/10/1999	NA	ND	ND
<i>QA/QC Samples</i>				
QA-1	06/10/1999	NA	ND	ND
PT-ERB-060799	06/07/1999	930	ND	ND

Notes:

J - estimated concentration below reporting limit
 ND - Not detected above the method detection limit
 NA - Not applicable

TABLE 9-4

SUMMARY OF LEAD AND CADMIUM IN GROUNDWATER EXTRACTED DURING AQUIFER TEST

Phase II Groundwater Evaluation
 NL Industries Superfund Site
 Pedricktown, New Jersey

Sample Designation	Date	Time	Total Lead	Dissolved Lead	Total Cadmium	Dissolved Cadmium
PT-1-060799	06/07/1999	1500	6.1	4.6	43.9	45.2
PT-2-060799	06/07/1999	1537	3.0	1.4B	45.7	46.3
PT-3-060799	06/07/1999	1630	1.7B	ND	47.8	48.3
PT-4-060799	06/07/1999	1730	2.7B	ND	46.2	46.1
PT-5-060899	06/08/1999	0130	6.6	ND	44.8	43.9
PT-6-060899	06/08/1999	930	2.2B	ND	42.9	42.9
PT-7-060899	06/08/1999	1720	1.6B	ND	42.2	41.5
PT-8-060999	06/09/1999	0130	9.3	5.3	41.0	38.7
PT-9-060999	06/09/1999	1020	3.4	ND	39.2	38.9
PT-10-060999	06/09/1999	1750	2.9B	ND	39.0	38.2
PT-11-061099	06/10/1999	0130	ND	ND	38.0	37.9
PT-12-061099	06/10/1999	930	7.0	1.5B	36.8	37.2
PT-13-061099	06/10/1999	1415	1.7B	1.2B	37.3	35.3
QA/QC Samples						
PT-DUPLICATE-061099	06/09/1999	--	ND	ND	36.4	36.2
QA-1	06/10/1999	--	4.5	ND	36.5	35.0
PT-ERB-060799	06/07/1999	930	5.5	0.94B	0.85B	ND

Notes:

- (1) Measurements obtained using portable field instruments
- (2) Turbidity reported in nephelometric turbidity units (NTUs)
- (3) pH reported in standard units (SU)
- (4) All concentrations in ug/L (ppb)

TABLE 9-5

SUMMARY OF GENERAL GROUNDWATER CHEMISTRY⁽¹⁾ DURING AQUIFER TEST

Phase II Groundwater Evaluation
 NL Industries Superfund Site
 Pedricktown, New Jersey

Sample Designation	Date	Time	Bicarbonate Alkalinity	Carbonate Alkalinity	Chloride	Sulfate
PT-1-060799	06/07/1999	1500	ND	ND	53.4	3750
PT-8-060999	06/09/1999	1330	ND	ND	46.4	3200
PT-13-061099	06/10/1999	1415	ND	ND	40	2920
<i>QA/QC Samples</i>						
QA-1 ⁽²⁾	06/10/1999	1420	ND	ND	40.3	2780
PT-ERB-060799 ⁽³⁾	06/07/1999	930	13.2	ND	4.9	1.2

Sample Designation	Date	Time	Total Phosphorous	Total Dissolved Solids	Total Suspended Solids
PT-1-060799	06/07/1999	1500	ND	5260	6.4
PT-8-060999	06/09/1999	1330	ND	4300	ND
PT-13-061099	06/10/1999	1415	ND	3780	ND
<i>QA/QC Samples</i>					
QA-1 ⁽²⁾	06/10/1999	1420	ND	3720	ND
PT-ERB-060799 ⁽³⁾	06/07/1999	930	0.12	153	ND

Notes:

- 1 - Results reported in milligrams per liter (mg/L)
- 2 - Blind duplicate sample of PT-13-061099
- 3 - Equipment rinse blank sample

TABLE 9-6

ESTIMATED PERFORMANCE OF PUMP AND TREAT TECHNIQUE

**Phase II Groundwater Evaluation
NL Industries Superfund Site
Pedricktown, New Jersey**

From mass calculations (Table 2-1):
 Mass of lead in groundwater = 9 lbs
 Mass of cadmium in groundwater = 14 lbs

From Capture Zone Evaluation (Section 12): Estimate average total groundwater extraction rate = 37 gpm = 0.05 mgd

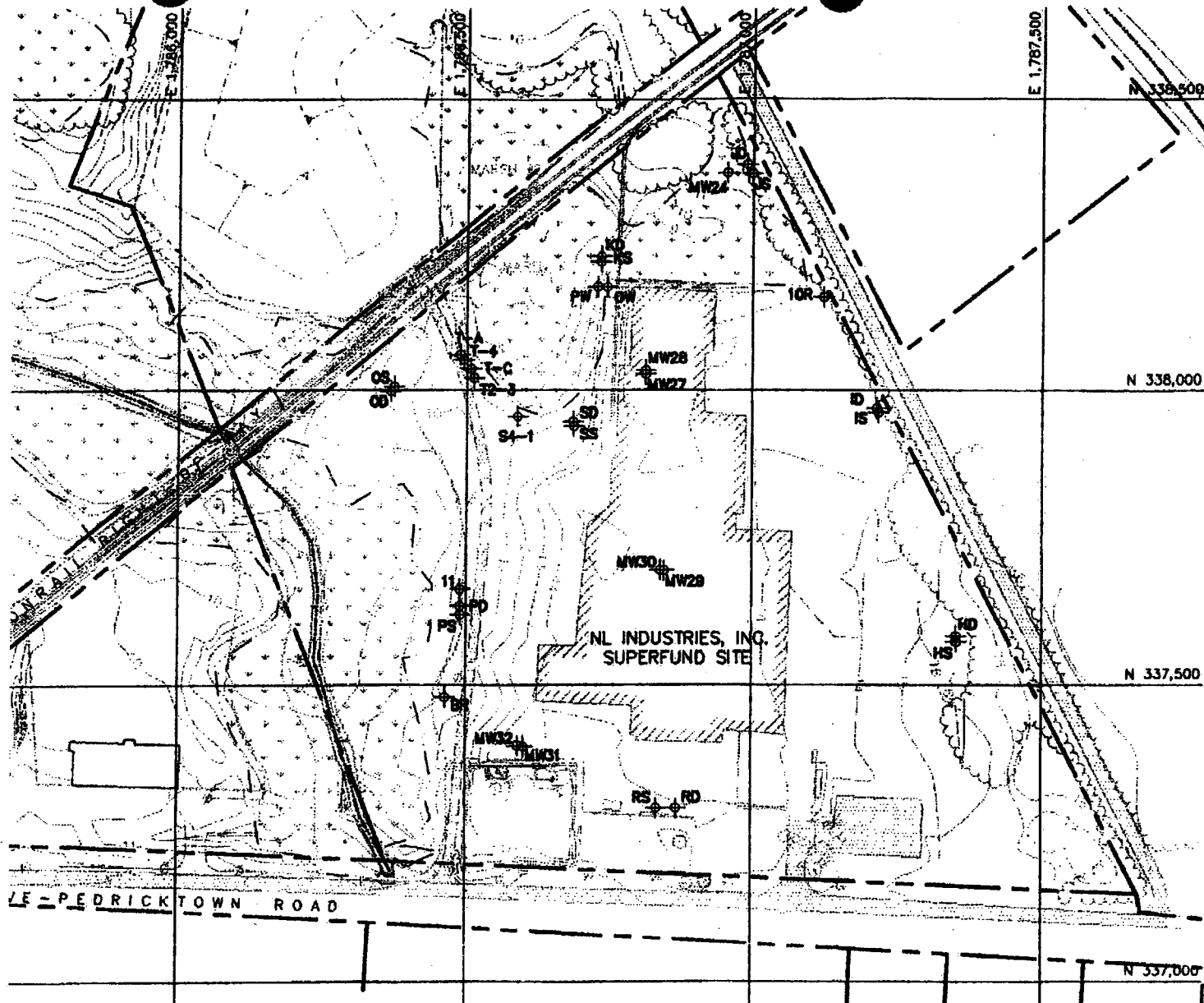
Time required to extract lead (if possible): $.001 \text{ mg/L} * 8.34 * 0.05 \text{ mgd} = 0.0004 \text{ lbs of lead per day extracted}$

$$\frac{9 \text{ lbs}}{0.0004 \text{ lbs/d}} = 225 \text{ days} = 61 \text{ years (if possible)}$$

Time required to extract cadmium (if possible): $.002 \text{ mg/L} \times 8.34 \times 0.05 \text{ mgd} = 0.0008 \text{ lbs of cadmium per day extracted}$

$$\frac{14 \text{ lbs}}{0.0008 \text{ lbs/d}} = 17,500 \text{ days} = 48 \text{ years (if possible)}$$

Note: Concentrations of lead and cadmium in extracted groundwater are expected to be non-detectable at steady state. Therefore, assume average concentrations of lead in extracted groundwater to be 1 ppb. For cadmium, assume the concentration will be up to 2 ppb to be conservative. It is possible that the concentrations of lead and cadmium in extracted groundwater will be lower than estimated.



LEGEND

- PROPERTY BOUNDARY
- CONTOUR OF EXISTING GROUND SURFACE (FT, MSL)
- EXISTING FENCE
- EXISTING RAILROAD LINE
- EXISTING TREELINE
- EXISTING STREAM
- EXISTING ROAD
- EXISTING WETLAND (SEE NOTE 4)
- APPROXIMATE LIMITS OF EXPOSED CONCRETE FOUNDATION
- EXISTING BUILDING
- MW27
- GROUNDWATER MONITORING WELL USED DURING AQUIFER TEST

200 100 0 200
SCALE IN FEET

WELL LOCATION PLAN FOR AQUIFER TEST



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PROJECT NO. MR0015-15	FIGURE NO. 9-1
DOCUMENT NO. -	FILE NO. 0015F108

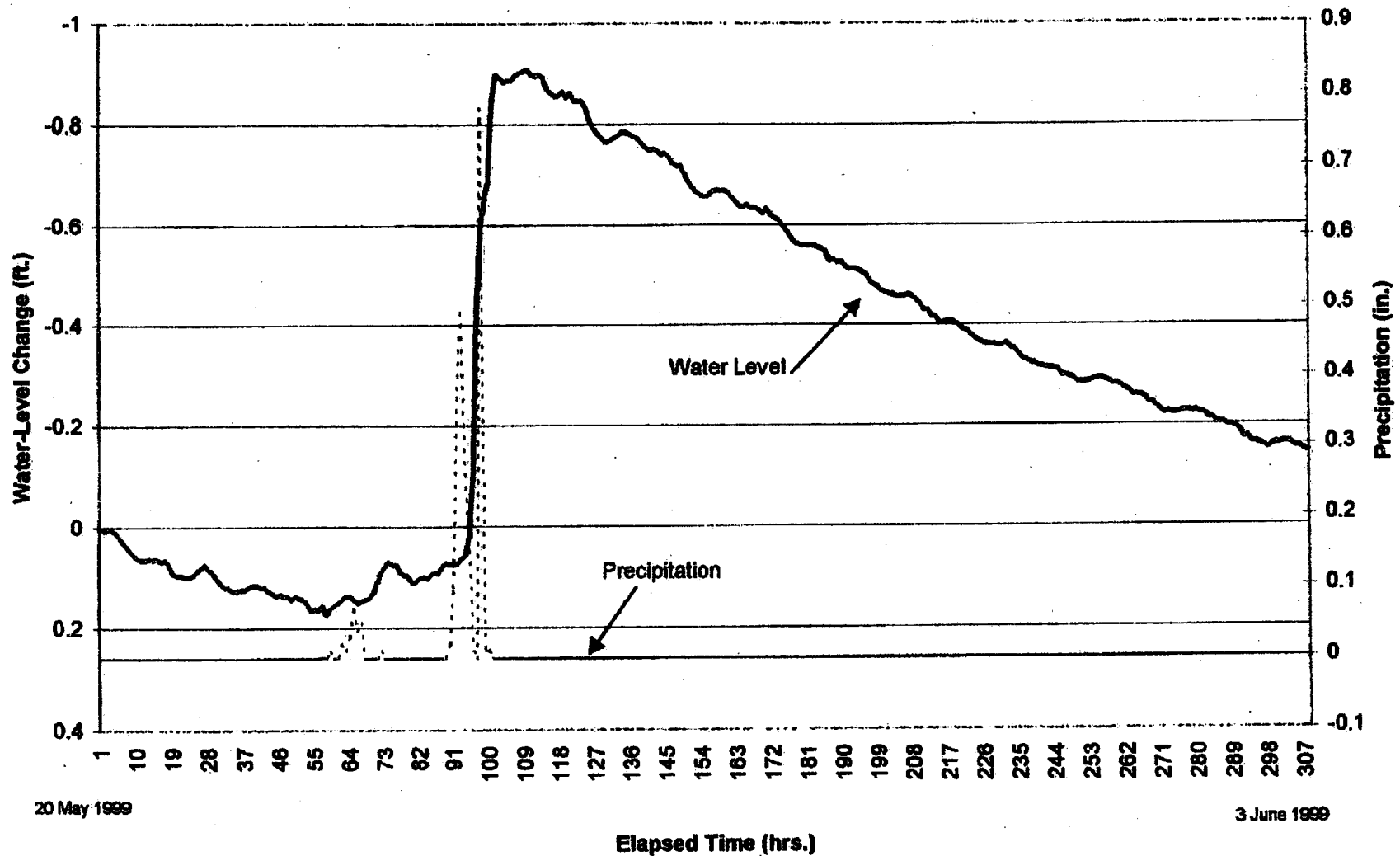
INDUSTRY IS APPROXIMATE AND IS BASED ON A TOPOGRAPHIC SURVEY BY ALBERT A. FRALINGER, BRIDGETON, NEW JERSEY, MAY 1990.

ALL ELEVATIONS ARE BASED ON AERIAL PHOTOGRAPHY AND GROUND SURVEY DATA COLLECTED ON 1 MARCH 1998 BY OHM REMEDIATION SERVICES CORP.

ALL DATA ARE BASED ON NATIONAL GEODETIC VERTICAL DATUM (NGVD) 1929. HORIZONTAL COORDINATES ARE BASED ON NEW JERSEY STATE PLANE COORDINATE SYSTEM.

4. WETLAND AREAS ALONG THE WEST STREAM WERE DELINEATED BY PENNONI ASSOCIATES, INC. FROM FIELD SURVEYS CONDUCTED BETWEEN 5 FEB AND 13 FEB 1999; ALL OTHER WETLANDS ARE BASED ON AREAS DELINEATED BY TALBOT & ASSOCIATES, DECEMBER 1990.

PRE-TEST WATER LEVEL CHANGES AT WELL OW

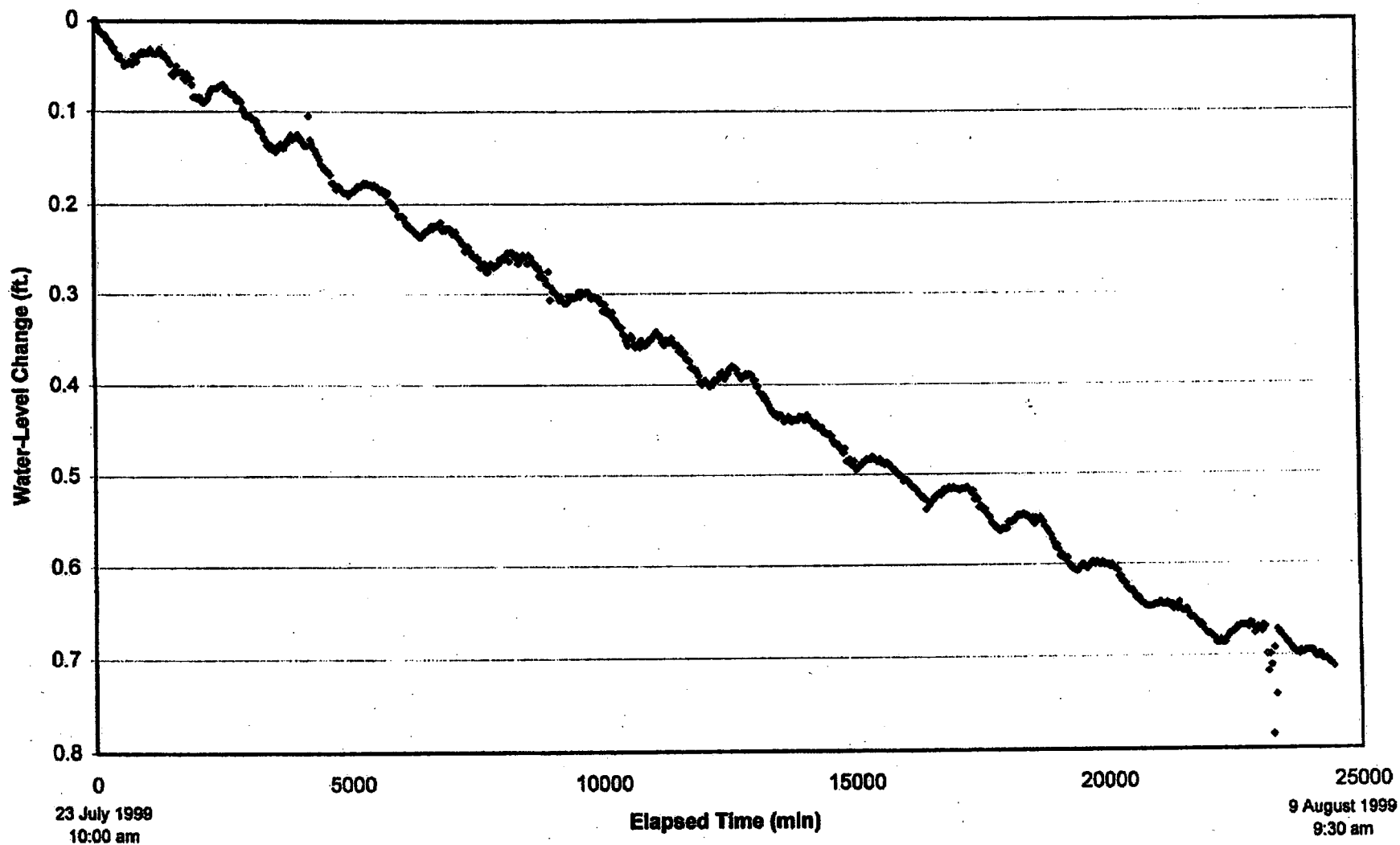


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-2
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

POST-TEST WATER LEVELS AT WELL PW

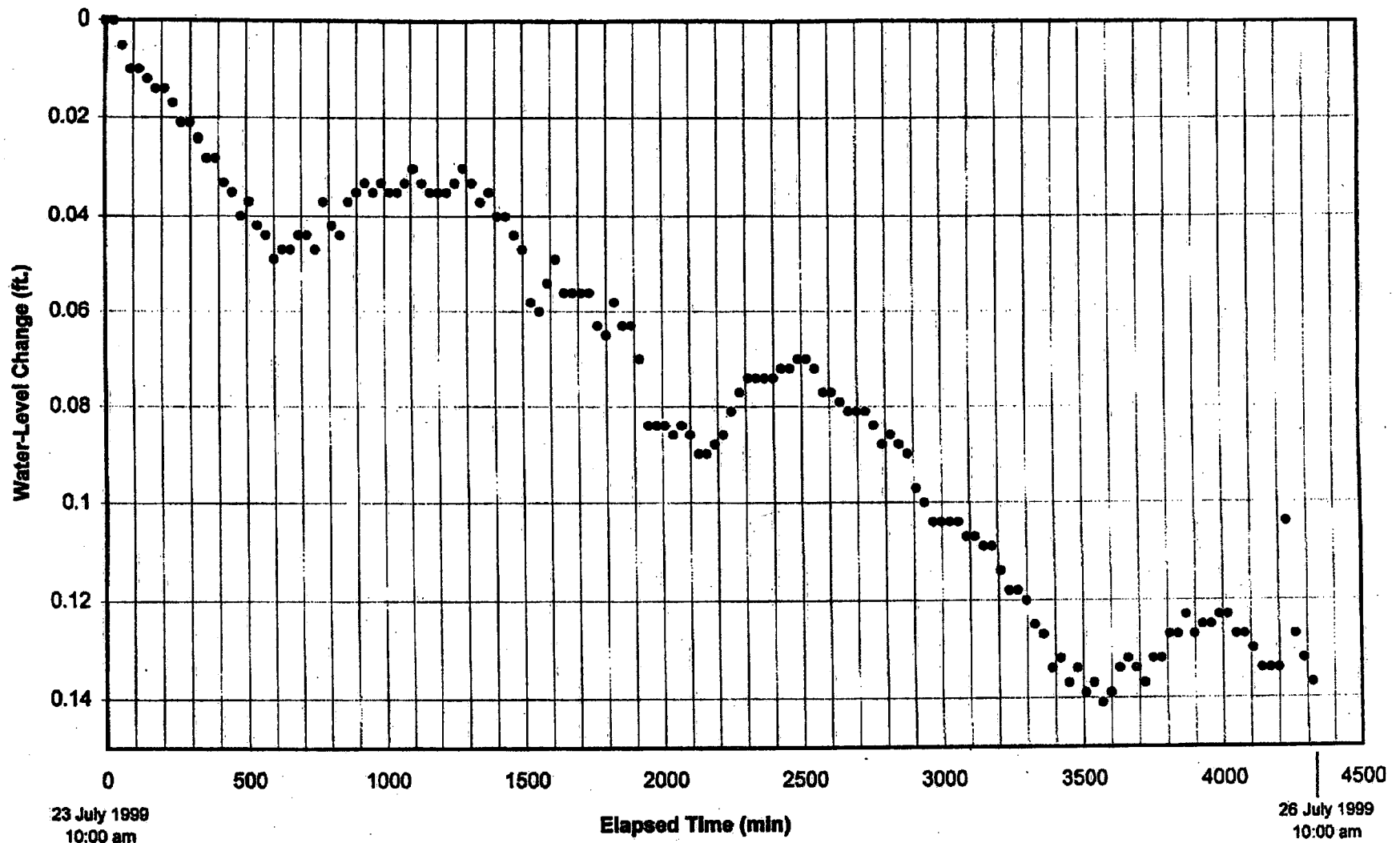


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-3
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

POST-TEST WATER LEVELS AT WELL PW (PARTIAL)

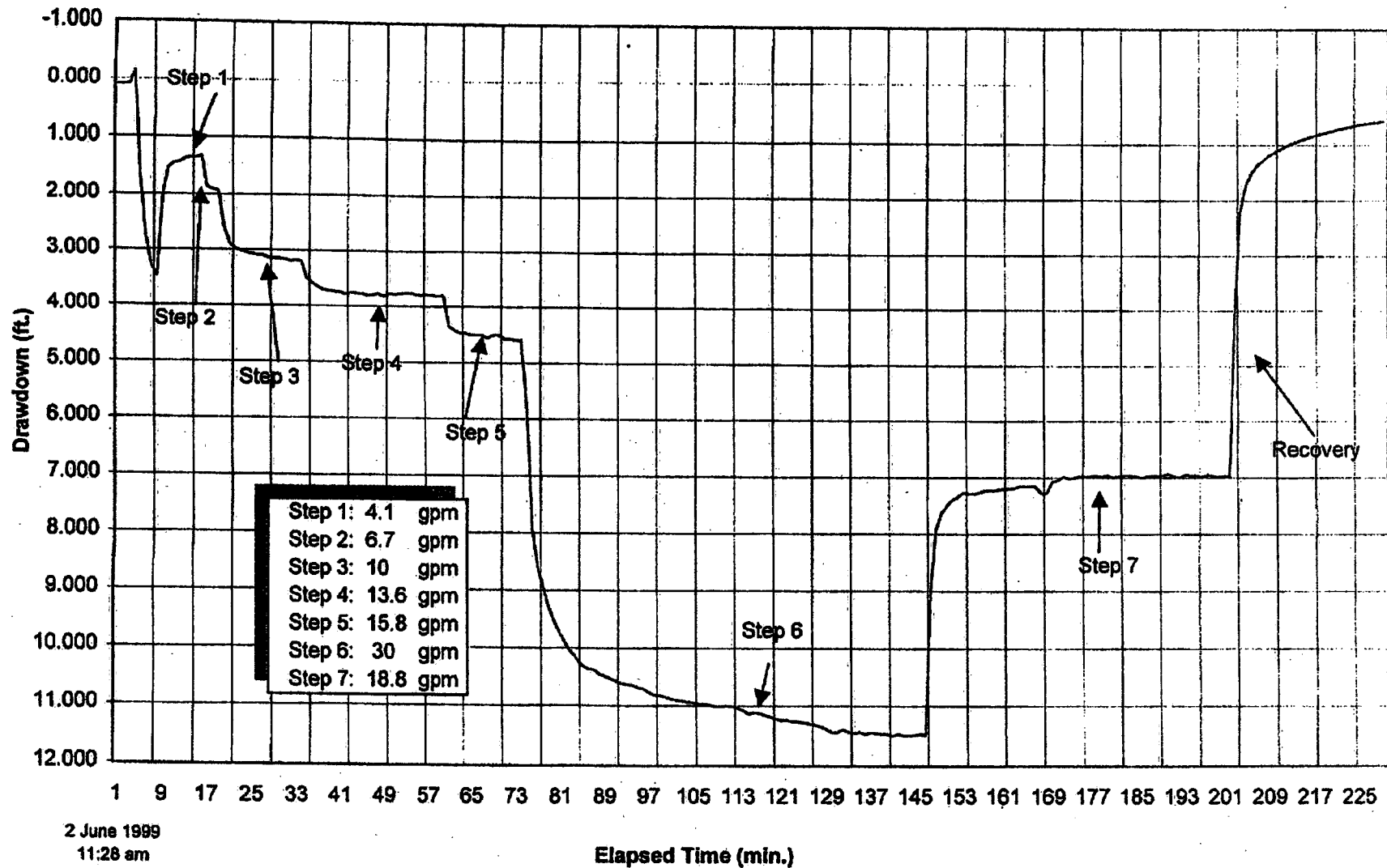


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-4
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

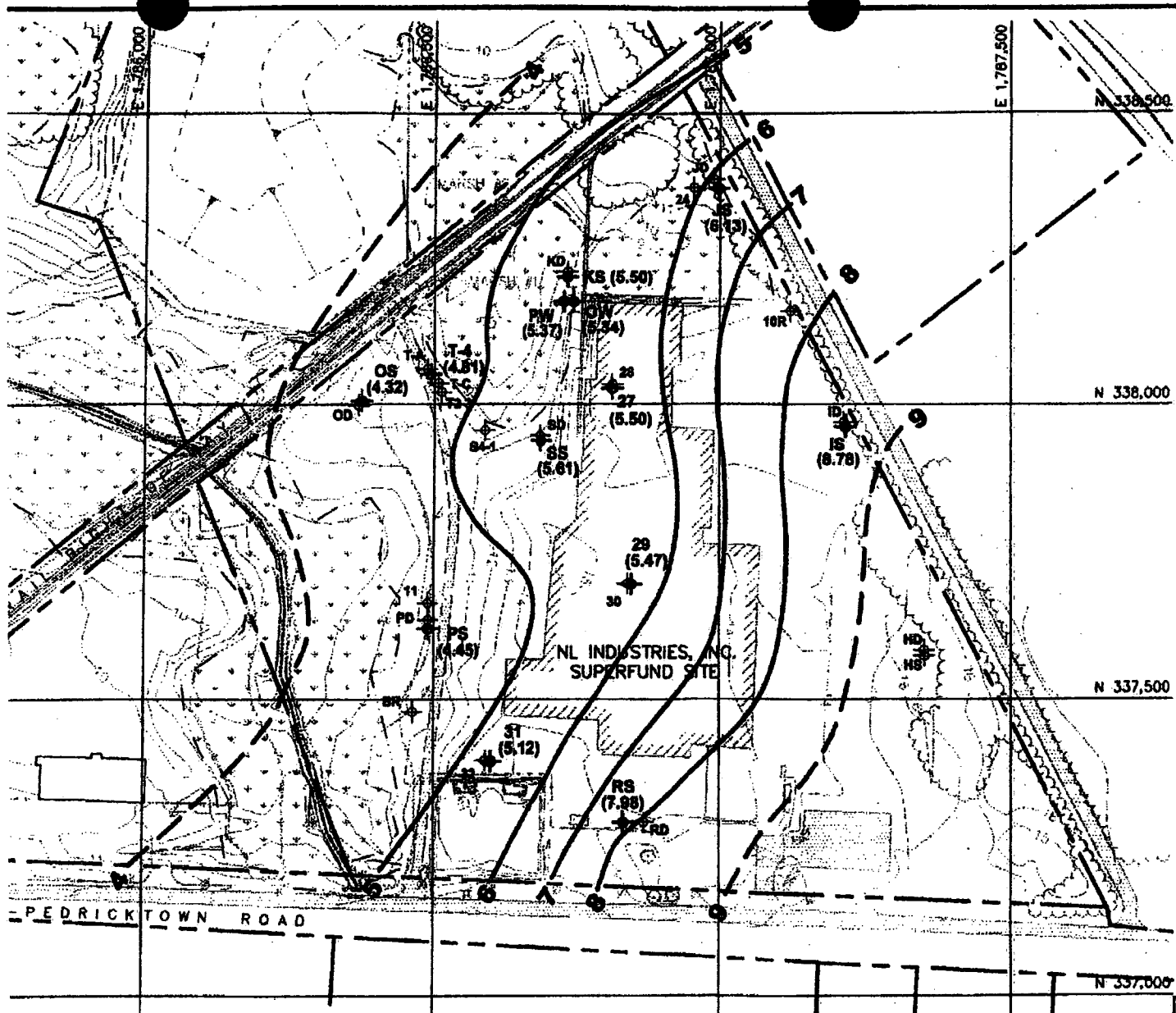
STEP-TEST HYDROGRAPH AT WELL PW



GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-5
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118



LEGEND

- PROPERTY BOUNDARY
- CONTOUR OF EXISTING GROUND ELEVATION (FT. MSL)
- EXISTING FENCE
- EXISTING RAILROAD LINE
- EXISTING TREELINE
- EXISTING STREAM
- EXISTING ROAD
- EXISTING WETLAND (SEE NOTE 4)
- APPROXIMATE LIMITS OF EXPOSED CONCRETE FOUNDATION
- EXISTING BUILDING
- POTENTIOMETRIC SURFACE CONTOUR (DASHED WHERE INFERRED)
- ⊕ 29 (5.47) GROUNDWATER MONITORING WELL USED DURING AQUIFER TEST
- (5.47) GROUNDWATER ELEVATION

200 100 0 200
SCALE IN FEET

Y IS APPROXIMATE AND IS BASED ON A TOPOGRAPHIC SURVEY BY A. FRALINGER, BRIDGETON, NEW JERSEY, MAY 1990.

ELEVATIONS ARE BASED ON AERIAL PHOTOGRAPHY AND GROUND DATA 1995 BY OHM REMEDIATION SERVICES CORP.

BASED ON NATIONAL GEODETIC VERTICAL DATUM (NGVD) 1929.
BASED ON NEW JERSEY STATE PLANE COORDINATE SYSTEM

4. WETLAND AREAS ALONG THE WEST STREAM WERE DELINEATED BY PENNOM ASSOCIATES, INC. FROM FIELD SURVEYS CONDUCTED BETWEEN 5 FEB AND 13 FEB 1990; ALL OTHER WETLANDS ARE BASED ON AREAS DELINEATED BY TALBOT & ASSOCIATES, DECEMBER 1990.

POTENTIOMETRIC SURFACE SHALLOW UNCONFINED AQUIFER 6/7/99 (PRE-PUMPING)

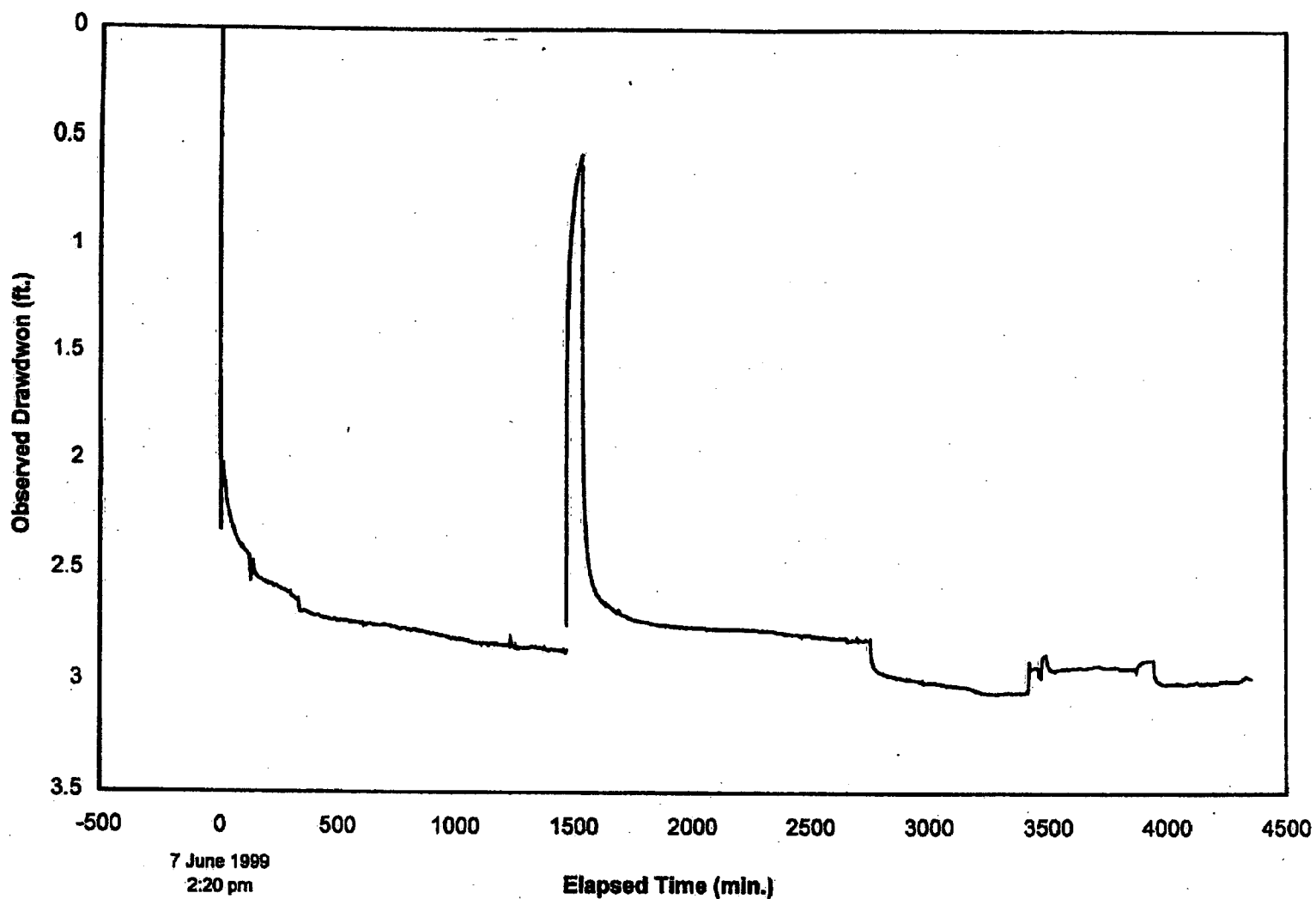


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COLUMBIA, MARYLAND

PROJECT NO. MR0015-15	FIGURE NO. 9-6
DOCUMENT NO. -	FILE NO. 0015F111

HYDROGRAPH AT OW (RAW DATA)

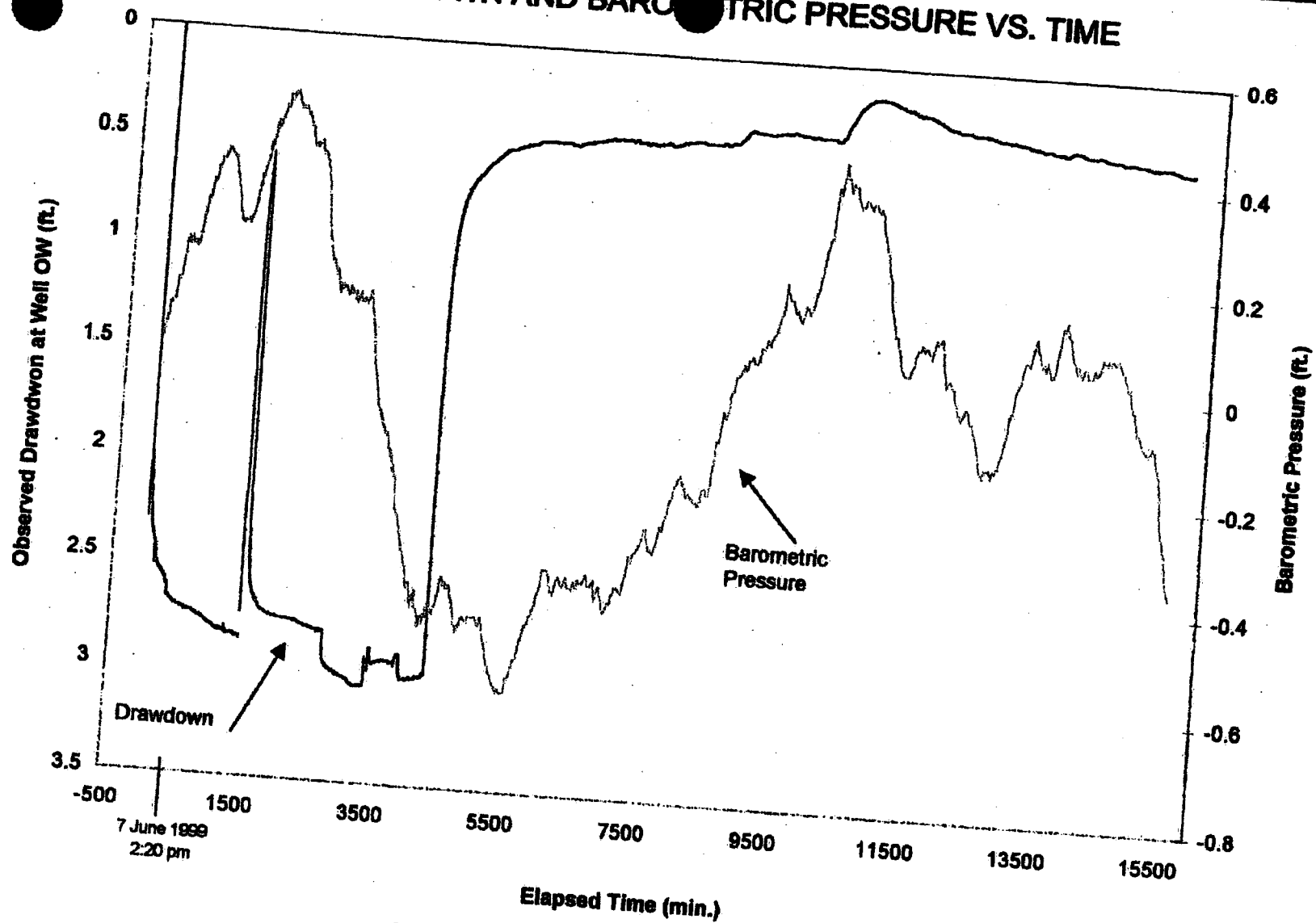


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

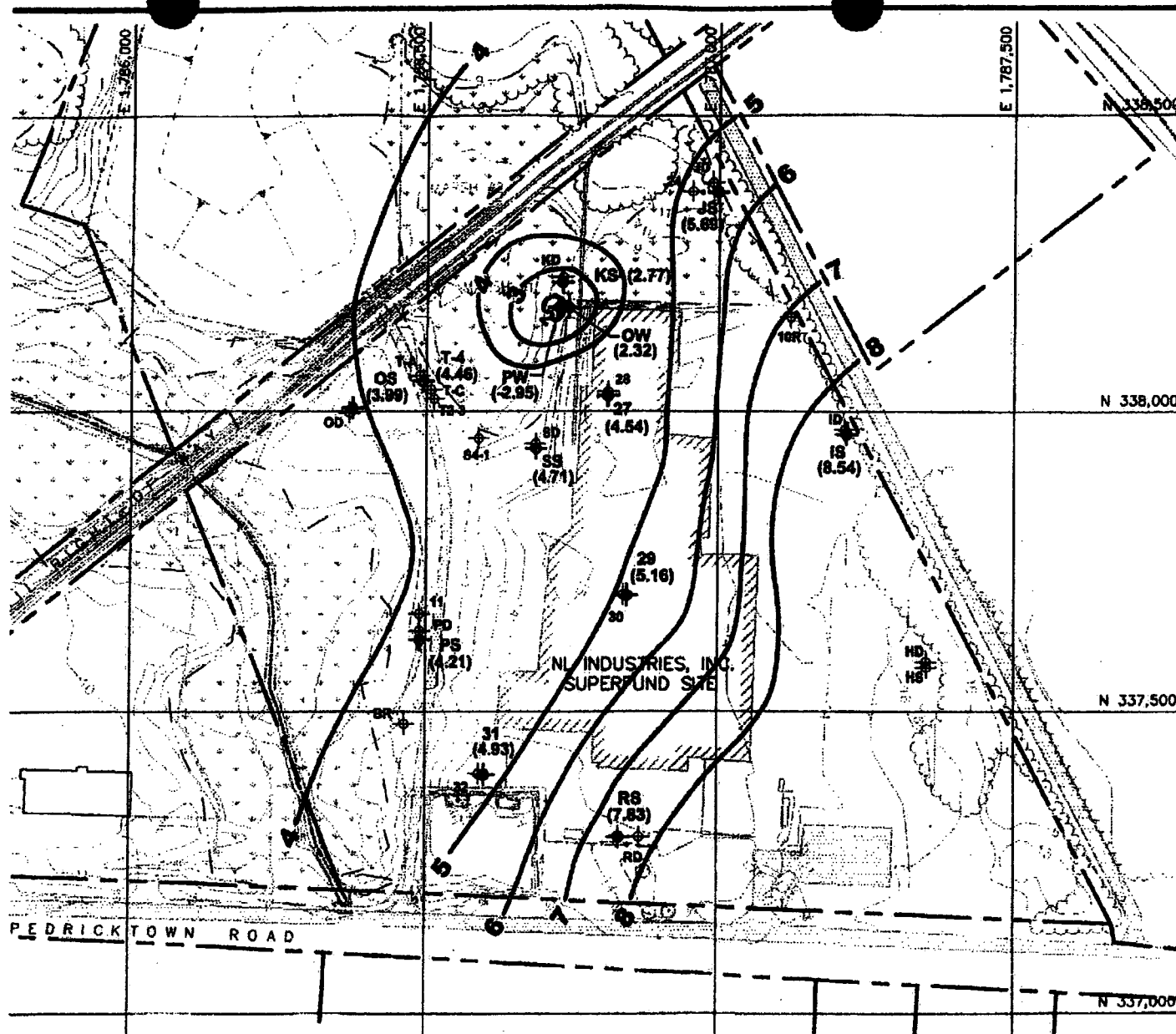
FIGURE NO.	9-7
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

DRAWDOWN AND BAROMETRIC PRESSURE VS. TIME



GEOSYNTEC CONSULTANTS
COLUMBIA, MARYLAND

FIGURE NO.	9-8
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118



LEGEND

- PROPERTY BOUNDARY
- CONTOUR OF EXISTING GROUND SURFACE (FT. MSL)
- - - EXISTING FENCE
- - - EXISTING RAILROAD LINE
- - - EXISTING TREELINE
- - - EXISTING STREAM
- [Hatched Box] EXISTING ROAD
- [Stippled Box] EXISTING WETLAND (SEE NOTE 4)
- [Dashed Line] APPROXIMATE LIMITS OF EXPOSED CONCRETE FOUNDATION
- [Outline Box] EXISTING BUILDING
- [Dashed Line] POTENTIOMETRIC SURFACE CONTOUR (DASHED WHERE INFERRED)
- [Well Symbol] GROUNDWATER MONITORING WELL USED DURING AQUIFER TEST
- [Elevation] GROUNDWATER ELEVATION

200 100 0 200
SCALE IN FEET

POTENTIOMETRIC SURFACE SHALLOW UNCONFINED AQUIFER 6/10/99 (PUMPING)



GEO SYNTEC CONSULTANTS

COLUMBIA, MARYLAND

PROJECT NO. MR0015-15	FIGURE NO. 9-9
DOCUMENT NO. -	FILE NO. 0015F112

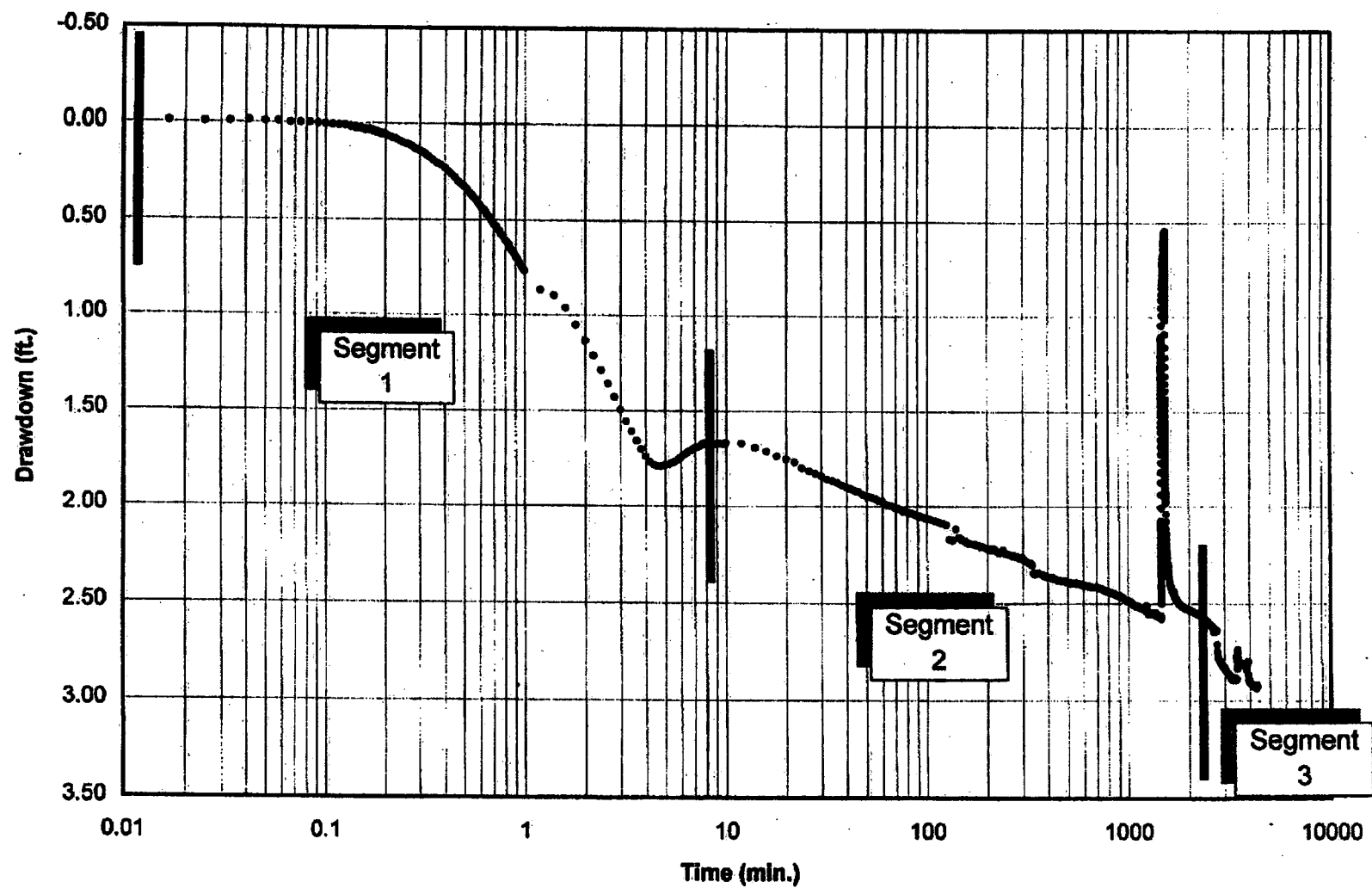
5. APPROXIMATE AND IS BASED ON A TOPOGRAPHIC SURVEY
A. FRALINGER, BRIDGETON, NEW JERSEY, MAY 1990.

6. DATA ARE BASED ON AERIAL PHOTOGRAPHY AND GROUND
1996 BY OHM REMEDIATION SERVICES CORP.

7. ON NATIONAL GEODETIC VERTICAL DATUM (NGVD) 1928.
BASED ON NEW JERSEY STATE PLANE COORDINATE SYSTEM

4. WETLAND AREAS ALONG THE WEST STREAM WERE DELINEATED BY PENNOM ASSOCIATES,
INC. FROM FIELD SURVEYS CONDUCTED BETWEEN 5 FEB AND 13 FEB 1999. ALL OTHER
WETLANDS ARE BASED ON AREAS DELINEATED BY TALBOT & ASSOCIATES, DECEMBER 1990.

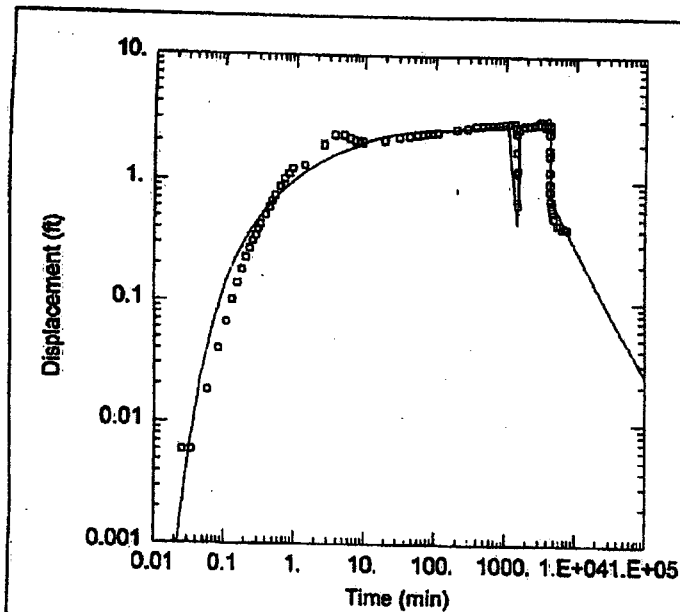
DRAWDOWN VS. TIME AT WELL KD



GEOSYNTEC CONSULTANTS
COLUMBIA, MARYLAND

FIGURE NO.	9-10
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

NEWMAN ANALYSIS AT WELL OW



WELL TEST ANALYSIS

Data Set: J:\WPWORK\DUANE\LPumping Test\OW-4.AQT
Date: 01/03/00 Time: 16:36:21

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman
T = 3828.6 gal/day/ft
S = 0.0005025
Sy = 0.04692
B = 0.004301

AQUIFER DATA

Saturated Thickness: 23. ft

WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
PW	0	0	OW	0	16.75

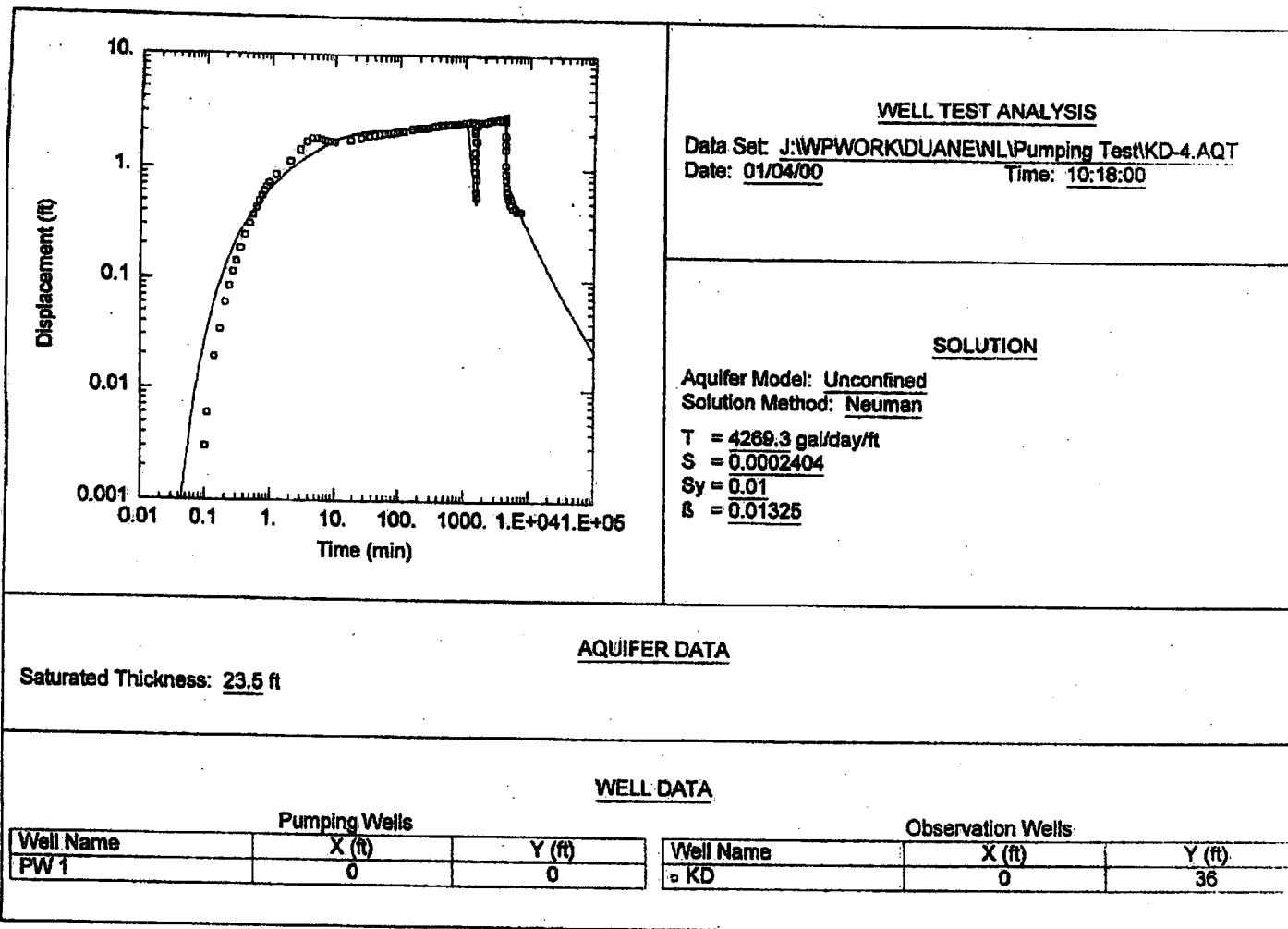


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-11
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

NEWMAN ANALYSIS AT WELL KD

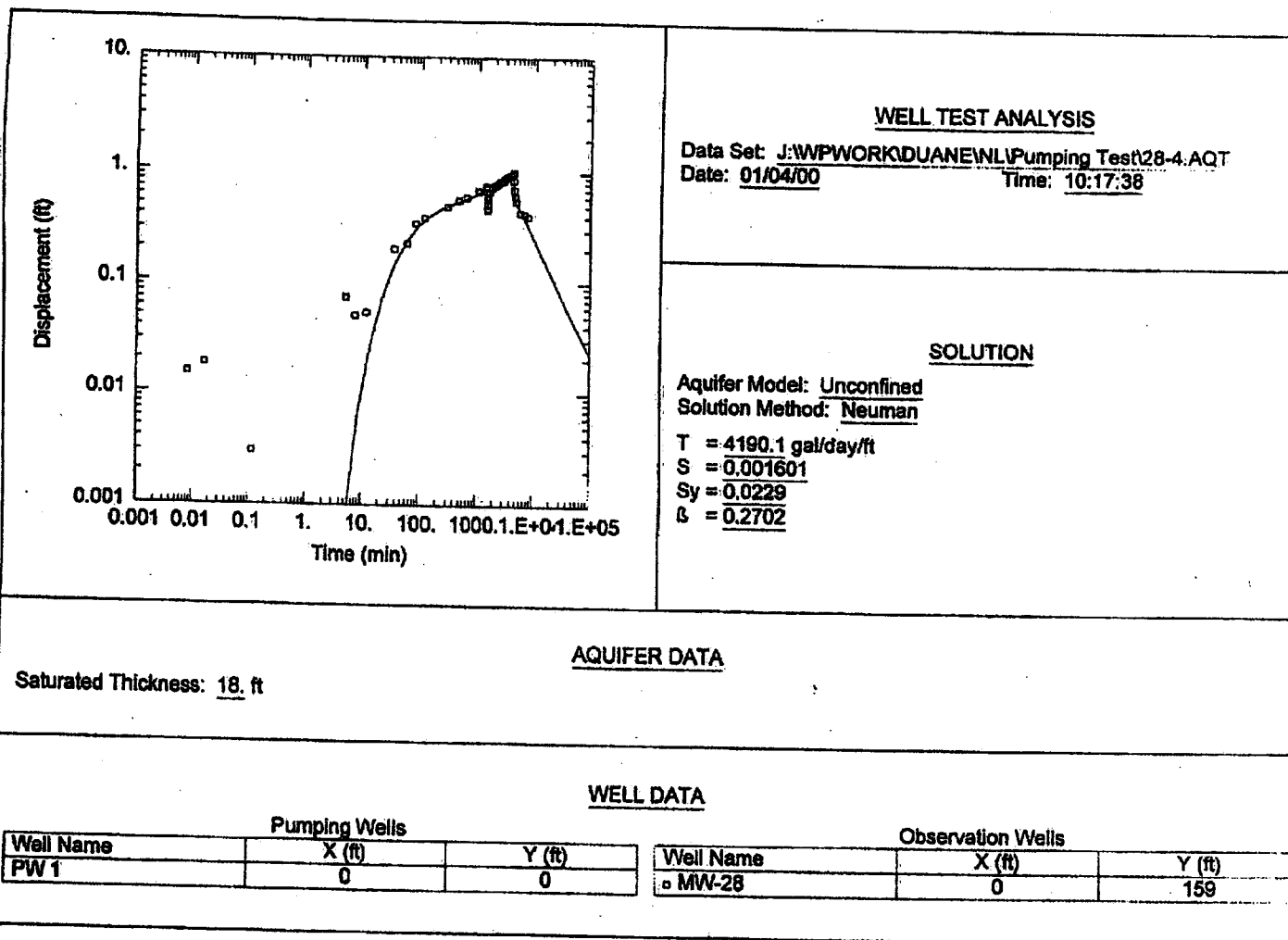


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-12
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

NEWMAN ANALYSIS AT WELL MW-28

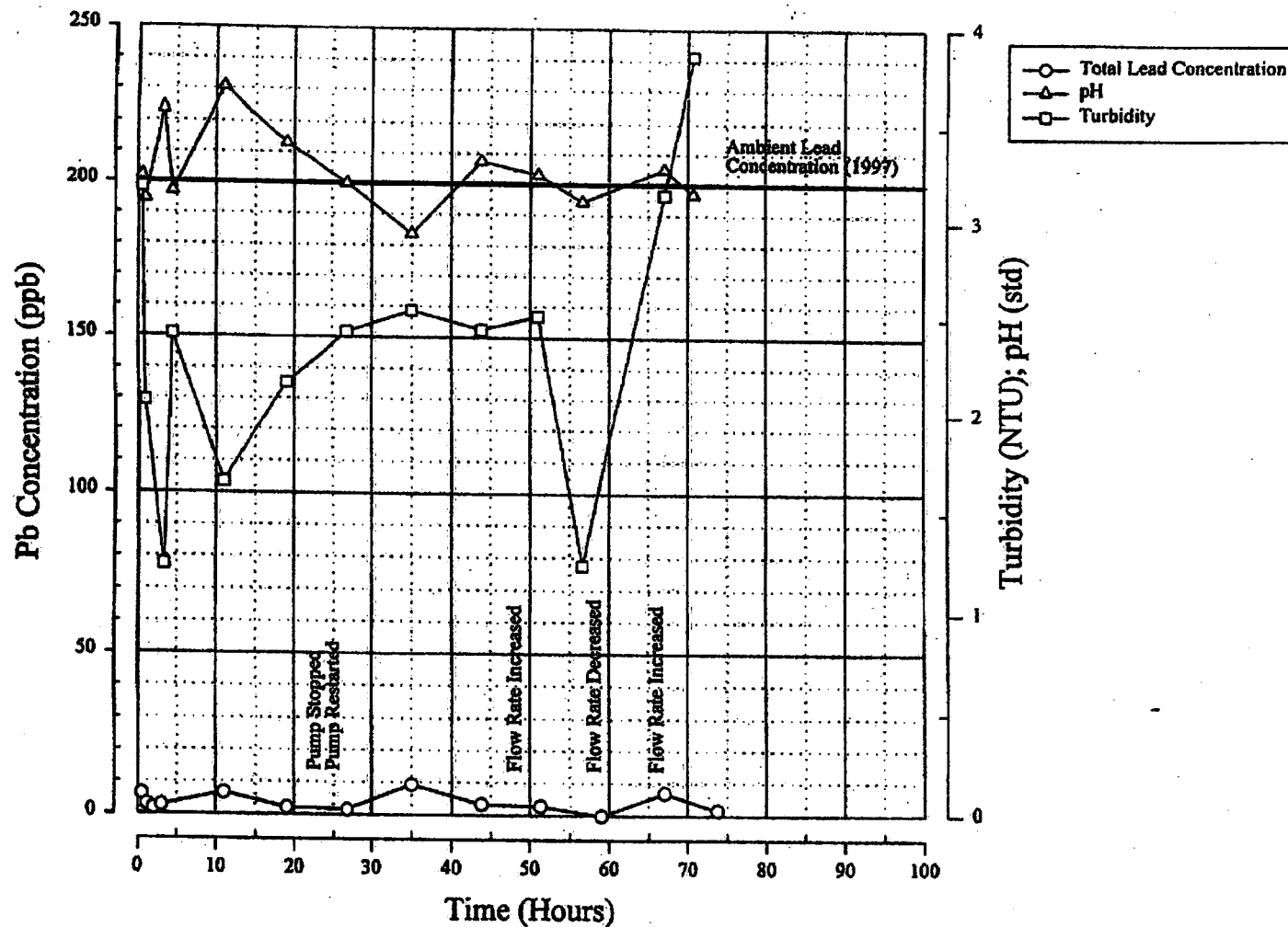


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-13
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

TOTAL LEAD MEASURED IN EFFLUENT DURING AQUIFER TEST

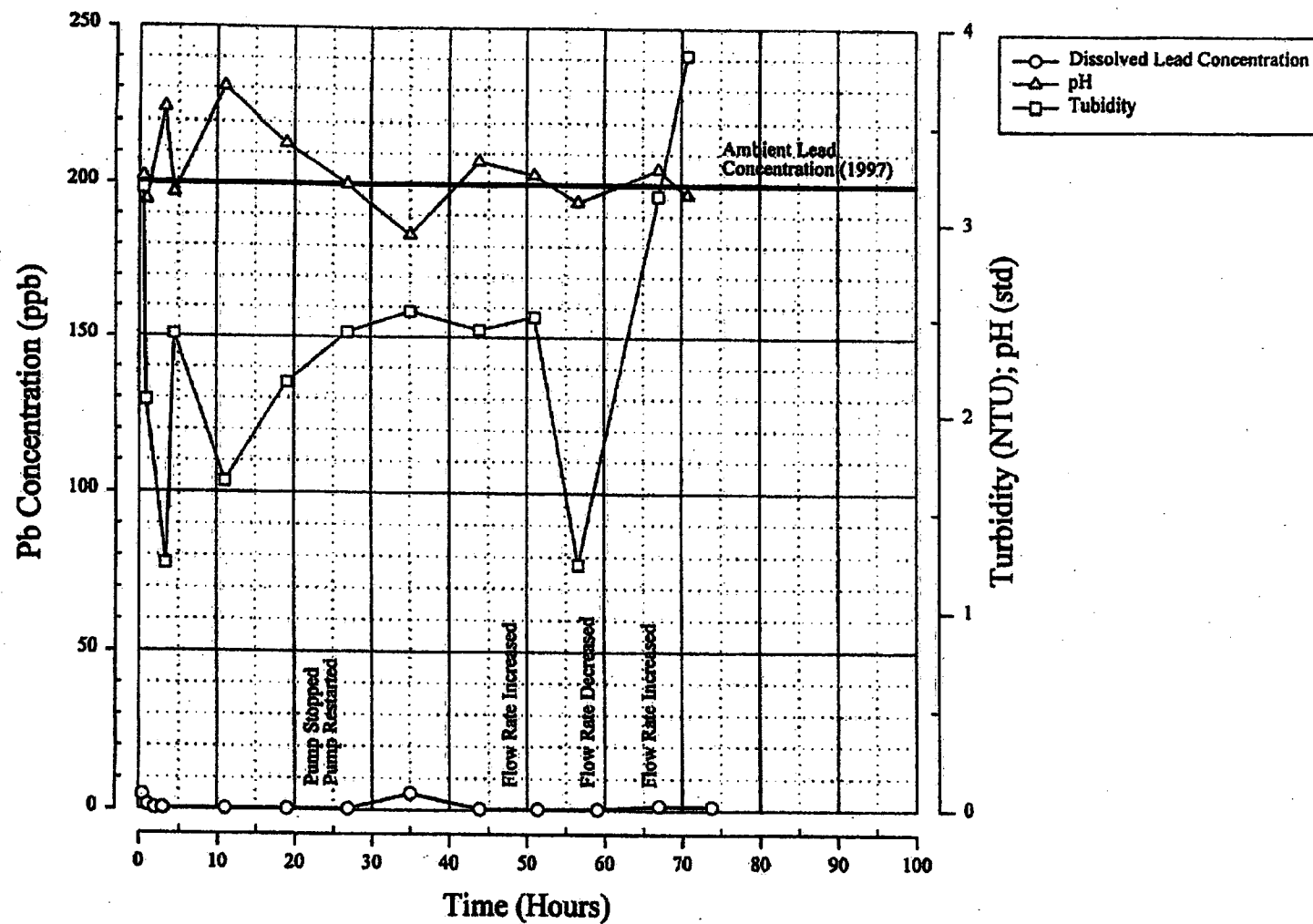


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-14
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

DISSOLVED LEAD MEASURED IN EFFLUENT DURING AQUIFER TEST

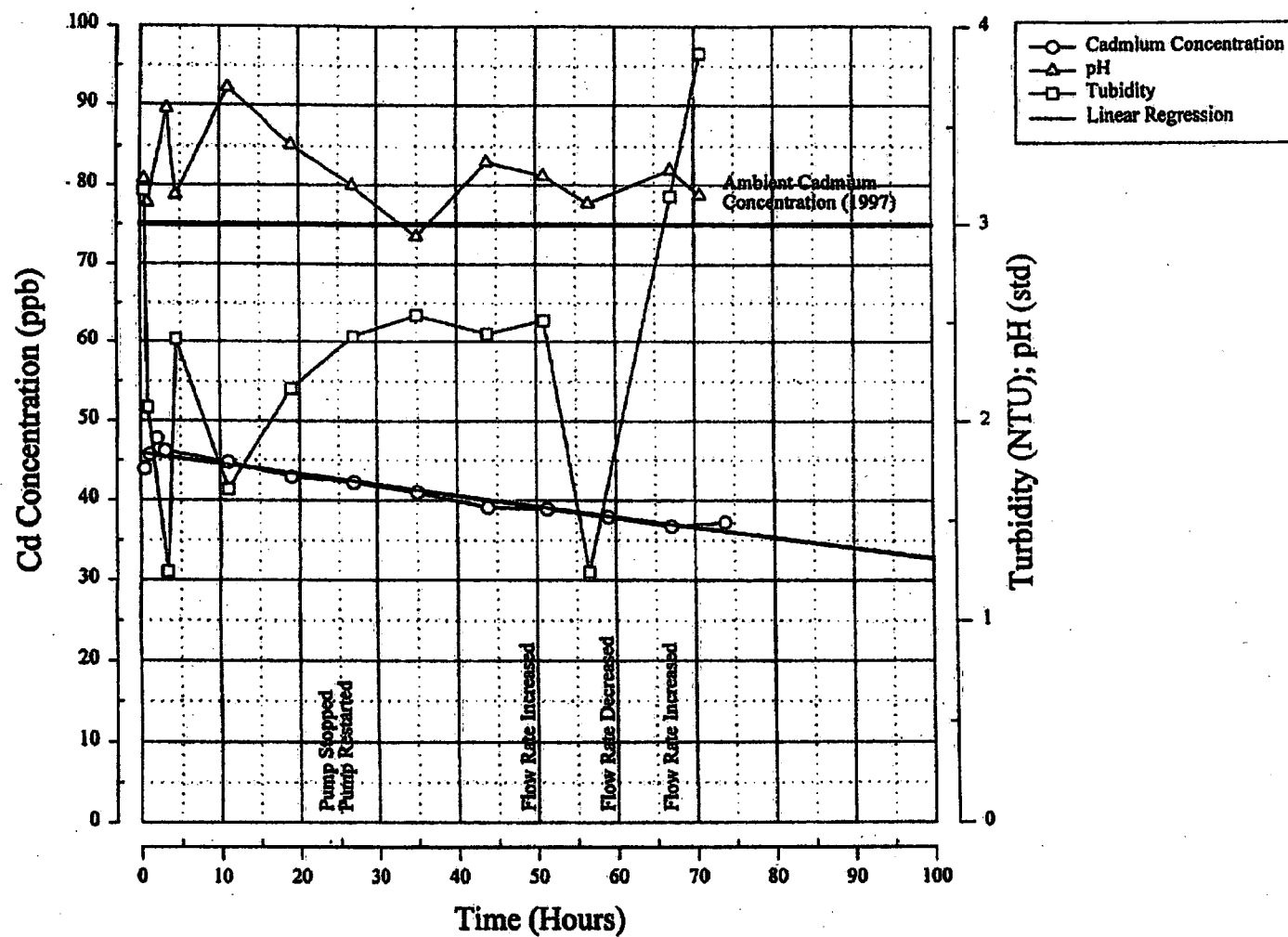


GEO SYNTec CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-15
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

TOTAL CADMIUM MEASURED IN EFFLUENT DURING AQUIFER TEST

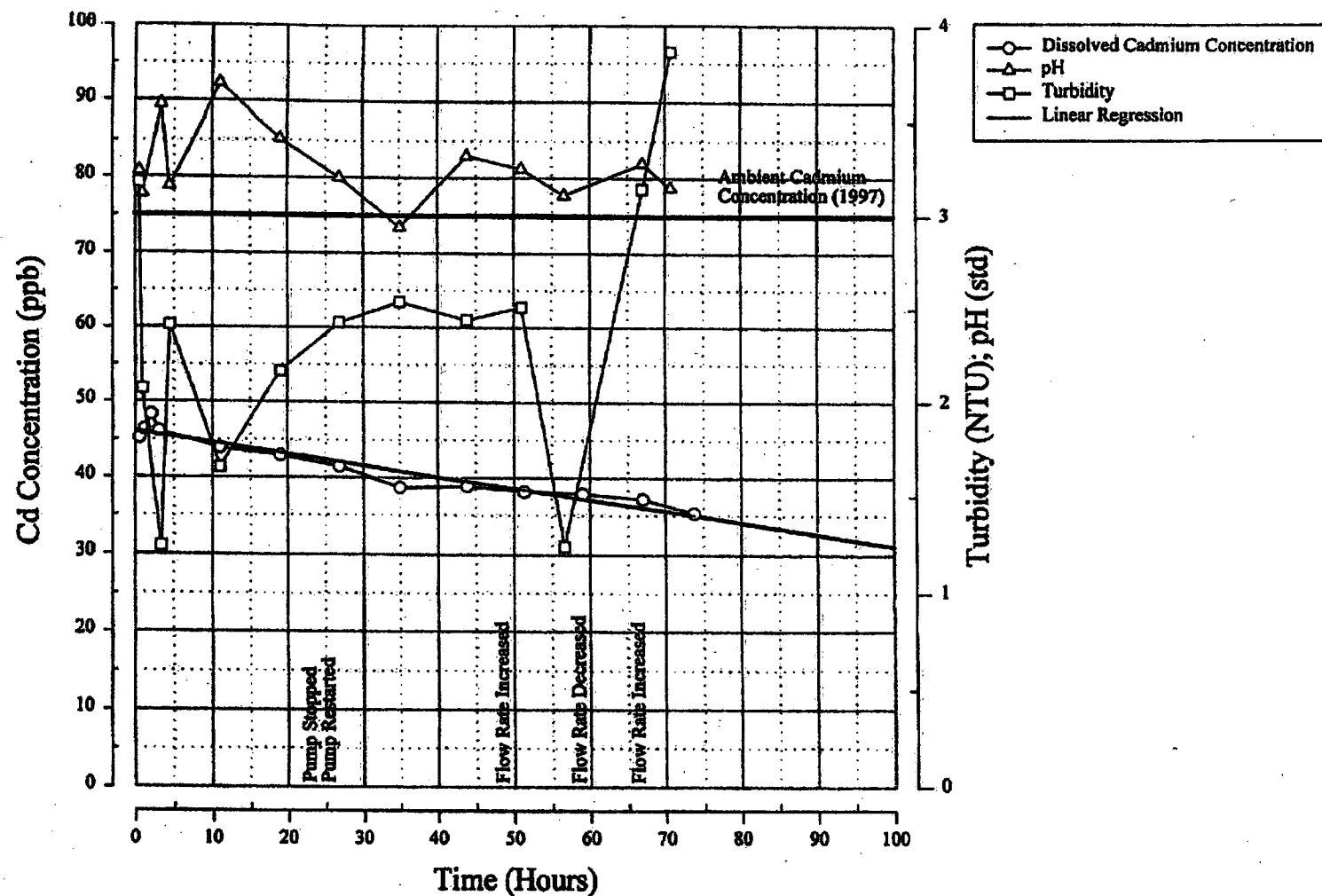


GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-16
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118

DISSOLVED CADMIUM MEASURED IN EFFLUENT DURING AQUIFER TEST



GEOSYNTEC CONSULTANTS

COLUMBIA, MARYLAND

FIGURE NO.	9-17
PROJECT NO.	ME0015-15
DOCUMENT NO.	
FILE NO.	0015F118